Patellar tendinopathy

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Etiology and treatment

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Ik kan alles aan, dankzij Hem die mij kracht geeft.
(Filippenzen 4: 13)

Contents

Chapter 1

General Introduction

Jumper's knee: A patient's story

Last year I moved from a team that plays at the regional level to one that plays at the national level. I went from training twice a week to training four times a week and also started with strength training. The training sessions of my new team were more intensive than the sessions I was used to. Besides playing volleyball I am also a university student and work two nights as a waiter in a restaurant. After playing for two months for my new team my knee became painful. The pain was located just below the kneecap. At first the pain was only present during warm-ups and after playing volleyball. After a while the pain was also present during games and it became impossible to play, so I rested for a month. Then I tried to start again with training, but the pain recurred. At this point I went to see my GP. He told me I had a jumper's knee and prescribed rest, NSAIDS and physical therapy. The physical therapist instructed me to perform eccentric exercises and after two months I was able to do decline squats without pain. I then decided to restart volleyball training, but again the pain recurred. As a result of this I missed the last part of the volleyball season. During the summer break symptoms diminished and at the beginning of the new season I was fully involved in the training sessions. After five weeks the pain came back, so I went to see my GP again. He gave me an injection with corticosteroids, which enabled me to train and play without pain. A few weeks later the pain returned and was even worse than before the injection. I am therefore not involved in volleyball at the moment. As long as I refrain from playing volleyball the pain is tolerable, but I would like to play again. I have searched the internet and talked to teammates, and several treatment options that include all kinds of injections, shockwave therapy and surgery are recommended. I am desperate as to what to do. Hey doctor, why did I get this bothersome injury and which treatment is going to be effective to get me to play again?

Introduction

Patellar tendinopathy (also called jumper's knee) is an injury that is characterised by activity-related pain in the patellar tendon, typically located proximally in the tendon just below the patella, although it can also be located distally in the tendon.[1] Patellar tendinopathy (PT) is a common injury among jumping athletes. Elite basketball and volleyball players show a prevalence of 30-45 % and recreational players of 10-15%.[2, 3] PT is a troublesome injury (see the patient's story) that may force athletes to end their sports career and can even keep causing mild but long-lasting symptoms after that.[4] Four phases of symptoms and functional impairment have been described: 1) pain after activity only, 2) pain at the start of activity and after activity, 3) pain during and after activity and inability to compete and 4) total rupture of the tendon.[5] These four phases can be distinguished clinically, but the underlying pathology forms a continuum.[6]

The patellar tendon

The function of a tendon is to transmit contractile forces from the muscle to the skeleton, to produce joint motion. Tendons have a hierarchical structure (figure 1). The smallest entity in a tendon is the microfibril. A group of microfibrils forms a fibril, the smallest structural unit. A group of fibrils in the extracellular matrix forms a fibre and a group of fibres bound together by endontenon forms a fascicle. Most fibres run in parallel with the long axis of the tendon. Fascicles are surrounded by epitenon. The paratenon forms the outer layer of the tendon.[7, 8]

A tendon is mainly composed of Type I collagen, and accounts for 95% of the total collagen. The second most present form of collagen is Type III collagen and is mainly found in the endotenon and epitenon. Type III collagen has less mechanical strength than Type I collagen, because it produces smaller and less organized fibrils.[7, 8]

The patellar tendon has, in contrast to many other tendons, no direct attachment to muscle tissue, but is attached at both ends to the skeleton through an osteotendinous junction. The patellar tendon has fibrocartilaginous insertions to the lower pole of the patella (figure 2A) and the tibial tuberosity (figure 2B). A fibrocartilaginous osteotendinous junction is composed of four zones: tendon, uncalcified fibrocartilage, calcified fibrocartilage and bone.[9] The fibrocartilage zones are thought to balance the different elasticity modes of tendon and bone.[10] Tendinopathy at the insertion of the quadriceps to the upper pole of the patella is not considered to be jumper's knee in this thesis and is therefore not addressed.[8]

Pathophysiology of (patellar) tendinopathy

Patellar tendinopathy used to be called patellar tendinitis and was thought to be an inflammatory condition. However, in the last decade there has been a paradigm shift towards the opinion that (patellar) tendinopathy is mainly a degenerative condition (tendinosis),[11] although some believe that inflammation (tendinitis) may play a role in (the early stages of) tendinopathy.[12] Because tendinosis can only be confirmed by means of histopathological examination, the term tendinopathy is often used in clinical practice.

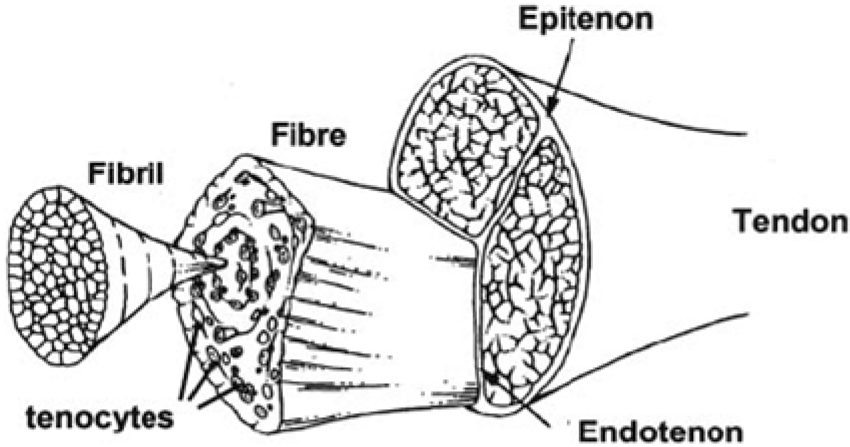
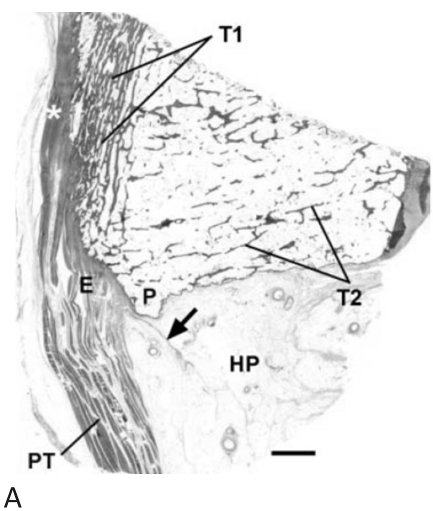


Figure 1. The hierarchical structure of a tendon. (Reproduced from Riley, The pathogenesis of tendinopathy: A molecular perspective, Rheumatology, 2004, 43 (2): 131-142, by permission of the British Society for Rheumatology.)



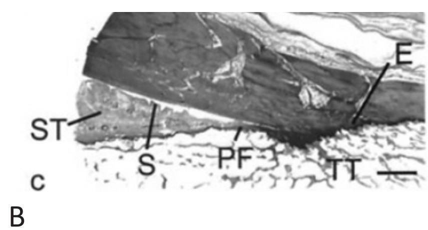


Figure 2. A. Section of the inferior pole of the patella (P), showing the enthesis (E) of the patellar tendon (PT) (HP = Hoffa's fat pad, T1 and T2 = trabeculae that run in superior inferior and anterior posterior direction).
B. Section of the distal enthesis (E) of the patellar tendon to the tibial tuberosity (TT) (PF = periostal fibrocartilage, S = synovium, ST = subsynovial tissue). (A: Reproduced from Journal of Anatomy, Toumi et al., 208, 47-57, 2006. B: Reproduced from Arthritis & Rheumatism, Benjamin et al., 50, 3306-3313, 2004, both with permission from John Wiley and Sons.)

Magnusson and Kjaer (2010) have suggested that tendinopathy is caused by a disbalance between the anabolic synthesis and the catabolic breakdown of the collagenous matrix of the tendon. A number of histological changes are found in the pathological tendon.[13] There are changes in cellularity (apoptosis), cell rounding, decreased matrix organisation and infiltration of blood vessels and accompanying nerves (neoneurovascularisations).[13-16] Besides histological changes there are also biochemical ones. Firstly, changes are found in matrix structure, such as an increase in the amount of type III collagen, and an increase in production of large-molecular proteoglycans such as aggrecan and versican. These proteoglycans bind water and contribute to the swelling of the tendon.[17] Secondly, there are changes in cytokines and signalling factors such as an increase in glutamate, substance P, calcitonin gene-related peptide (CGRP) and vascular endothelial growth factor VEGF (VEGF). And thirdly, changes have been found in concentrations of enzymes such as matrix metalloproteinases (MMPs) and a disintegrin and metalloproteinases (ADAMs) that play a role in matrix remodelling. These changes, however, do apply to tendinopathy of the main body of the tendon whereas most overuse injuries to the patellar tendon (also) involve the insertion sites where the tendon connects to the bone (osteotendinous junctions). In approximately 85% of the cases the proximal insertion (figure 2A) is affected and in 15% the distal (tibial) insertion (figure 2B).[18] Reasons why the osteotendinous junction is often affected are the low flexibility, the arrangement of fibres in relation to the direction of muscle force, and a small insertion zone compared to muscle size.[8]

The continuum model of tendinopathy distinguishes three phases of tendinopathy that form a continuum (figure 3).[6] The first phase is *reactive tendinopathy*, characterised by increased tendon thickness as a result of acute overload. The increase in tendon thickness reduces the stress placed on the tendon. There are no changes in collagen integrity in this phase. The second phase is *tendon disrepair*, which presents greater matrix changes. There is a separation of collagen, a disorganisation of the matrix and an increase in cells. There may also be an increase in vascularity and neuronal ingrowth in the tendon. The last phase is that of *degenerative tendinopathy*, in which the disorganisation of the matrix is more widespread. Because of acellularity (a result of apoptosis), the matrix is filled with vessels, matrix breakdown products and little collagen. The model presents a continuum with overlap between stages. The last stage, degenerative tendinopathy, is thought to be irreversible. The model is based on clinical, imaging and histopathological knowledge, and does justice to the observation that there are varieties in tendinopathy. The

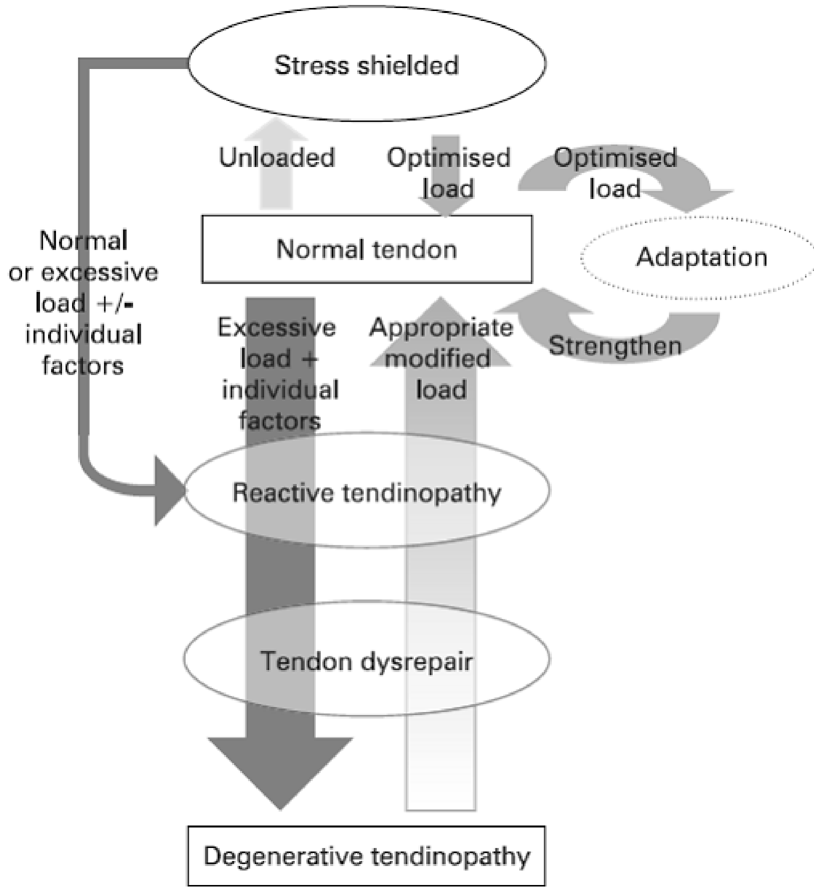


Figure 3. The continuum model of tendon pathology. (Reproduced from British Journal of Sports Medicine, Cook & Purdam, 43, 409-416, 2009 with permission from BMJ Publishing Group Ltd.)

model is still hypothetical and further research is required to validate it.

Several theories have been proposed about what causes tendinopathy. Rees et al. (2009) distinguished three theories that are not mutually exclusive: the mechanical theory, the vascular theory and the neural theory.[19] According to the mechanical theory, micro-injuries in the tendon resulting from overload and a subsequent failed healing process can eventually lead to matrix and cellular changes as well as to altered mechanical properties of the tendon. Besides overload, underloading of a tendon can also cause pathology. Another theory, a variant of the mechanical theory and specific for PT, is that the primary cause are compressive loads (caused by impingement) rather than tensile loads.[20] These compressive forces at the proximal posterior part of the patellar tendon cause histological changes as a result of an adaptive process. This causes more tensile stress to be placed on the surrounding tendon tissue, leading to overload of this tissue. This theory is in line with the finding that the maximal tensile strain is not found at the posterior side of the proximal tendon, which is the most common site for PT.[21] The vascular theory places the cause of tendinopathy in poor blood supply to tendons. This theory addresses mainly the supraspinatus, Achilles and tibialis posterior tendons, which are thought to have certain avascular areas. However, it has been debated whether these avascular areas actually exist.[19] The neural theory suggests that the release of neurotransmitters such as substance P and glutamate may cause pain. These theories are not mutually exclusive and may all explain the pathophysiology of PT to a certain extent, but further research is needed to determine if and how such mechanisms play a role in this pathophysiology.[19]

Pain in patellar tendinopathy

It is not clear yet what causes pain in tendinopathy. Early theories suggest that pain is caused either by an inflammatory condition (tendinitis) or by separation of collagen fibres such as in ligament injury.[22] As already discussed, tendinopathy is not considered to be an inflammatory condition, therefore this is unlikely to be the cause of the pain. Furthermore, although injury to the collagen fibres plays a role in the pain associated with tendinopathy it does not explain the pain mechanism completely, because a number of studies have shown that there is no relation between collagen structure and pain.[22, 23] The pain must thus be sought elsewhere, and it has been suggested that biochemical substances, such as glutamate and substance P, may be causing the pain by irritating nociceptors.[22, 23] Neovascularisations (with accompanying nerves) may also play a role in the pain mechanism.[24, 25] In a population of subjects with patellar tendon imaging abnormalities it was shown that persons with neovascularisations in their tendons experienced more pain than those without.[26] Some studies have shown however that these neovascularisations are also present in asymptomatic subjects,[27] while others have shown that neovascularisations are not related to pain in reactive tendinopathy, given that pain precedes them.[28] Somatosensory changes may also explain the pain in PT to a certain extent as it has been found that subjects with PT often show sensitisation, which leads to allodynia (pain due to a stimulus that normally does not cause pain) and hyperalgesia (an increased pain response).[29] PT may already exist for a long time before the onset of symptoms. Also, when symptoms disappear pathology may still

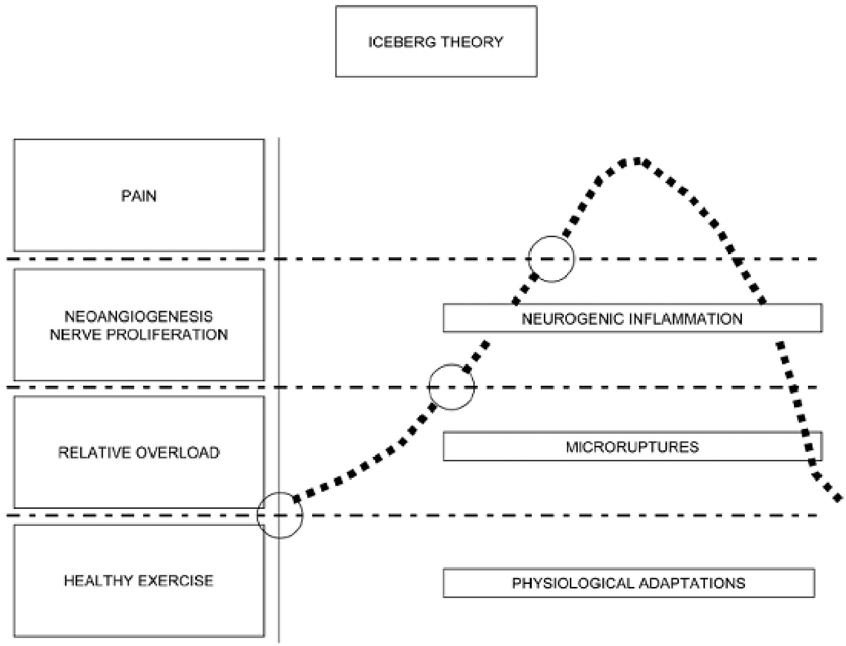


Figure 4. The iceberg theory. (Reproduced from Arthritis Research & Therapy, Abate et al., 11:235, 2009 with permission from Biomed Central.)

be visible on imaging. This phenomenon is called the 'iceberg theory': the pathology is often present below the pain threshold (figure 4).[12, 30]

Etiology and prevention

Since PT causes long-lasting symptoms and may force athletes to give up their sports participation, prevention of this injury is important. Finch (2006) developed a framework for sports injury prevention called TRIPP (Translating Research into Injury Prevention Practice).[31] The framework consists of 6 stages (figure 5). According to this framework the first step towards prevention is injury surveillance in order to describe the magnitude of the problem. For PT a number of studies have been published that address this first stage.[2, 3, 32] The second stage of the TRIPP framework is understanding of the etiology of an injury. Research into this stage should focus on risk factors that can be identified in epidemiological studies and injury mechanisms that require biomechanical studies. In the following stages of the TRIPP model (stages 3-6), the knowledge gained in the second stage can be used to develop evidence-based preventive measures. Several studies have addressed the second stage of the framework and a vast number of possible risk factors has been suggested. This makes it difficult to draw conclusions as to what are the most important risk factors. Also, most research has focused on elite athletes, therefore the second stage of the framework needs to be further addressed.

Management

The diagnosis of PT is a clinical one and is based on a combination of physical examination, history-taking and imaging.[33] A difficulty with imaging is that tendon abnormalities are not always accompanied by symptoms and changes in symptoms do not always correlate with structural changes.[34-36] The VISA-P questionnaire is often used to assess the severity of PT. It measures pain, function and sport participation in subjects with PT.[37]

Because risk factors are unclear, prevention of PT often fails. For this reason, besides research into these risk factors effective treatment to recover from PT is essential. With the paradigm shift from tendinitis to tendinosis, there has also been a shift away from treatments that focus on anti-inflammation, such as NSAIDs and corticosteroid injections, towards treatments that target the degeneration of tendon tissue.

According to Kountouris and Cook (2007), a tendinopathy rehabilitation program should consist of three essential components.[38] The first component is modifying tendon load to diminish symptoms. Although load reduction is important, total rest and unloading of the tendon is not advisable. Activity is thought to be better for regeneration of tendon tissue than inactivity,[39] because inactivity decreases collagen synthesis.[40, 41] Muscle-tendon function as well as pelvic and lower limb kinetic chain function should also be assessed. When the first goal (diminishing symptoms and addressing the kinetic chain, e.g. ankle dorsiflexion range (Backman et al. 2011)[42]) is reached, there is room to place load on the tendon and to move to the second component: exercise-based rehabilitation and adapting the tendon to increasing load. Eccentric exercises are the most common exercises used in an exercise-based rehabilitation program. They were first introduced to treat mid-portion Achilles tendinopathy.[43] Eccentric exercise may have a positive effect on PT, with a 50-70% chance of improvement.[44] It is not exactly clear why eccentric exercises are effective, but it may be related to high-frequency oscillations in tendon force during the eccentric phase as Rees et al. (2008) showed for the Achilles tendon.[45] The general consensus is that when performing eccentric exercises for PT a decline board should be used, some pain should be experienced, and subjects

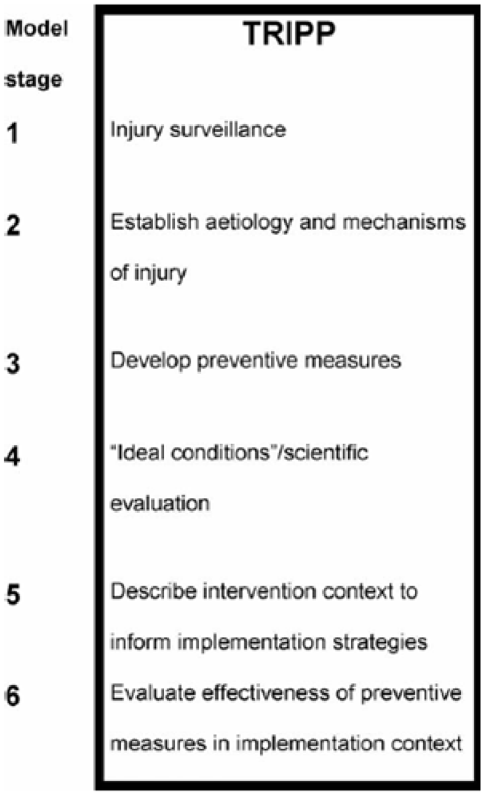


Figure 5. The Translating Research into Injury Prevention Practice (TRIPP) framework. (Reprinted from Journal of Science and Medicine in Sport, Volume 9, Finch, A new framework for research leading to sports injury prevention, 3-9, 2006, with permission from Elsevier.)

should avoid sports activity during the exercise period.[44] A recent study however found heavy slow resistance training, including both a concentric and an eccentric phase, to be more effective in improving symptoms than eccentric exercises.[46] This implies that both the concentric and the eccentric phase may have a positive effect on the tendon. According to Cook it is important to avoid exercises that use the elastic function of the tendon.[47, 48] This indicates that resistance training at low speeds may be beneficial.

The third component of the rehabilitation program outlined by Kountouris and Cook consists of additional treatment options. They mention addressing foot pronation/supination, ankle mobilisation and increasing hamstring and quadriceps flexibility. There are a number of other options described in the literature.[49] One of them is Extracorporeal Shockwave Therapy (ESWT) a non-invasive treatment option for tendinopathy that uses high-pressure waves to generate a mechanical

effect on the tendon tissue. In a review of the literature it was concluded that ESWT is a safe and promising method for treating PT, but that further research was required.[50] Later it was shown that ESWT is not effective in subjects that have symptoms for less than a year and who continue to participate in their sport.[51]
Another treatment option is the injection of a substance in or around the patellar tendon. A number of substances can be injected, such as, steroids, polidocanol, aprotinin, and platelet rich plasma (PRP). Several studies have been conducted that looked at the effectiveness of these injections yet the necessary scientific evidence is missing in all of them.[52] Only for steroids is there some evidence for a positive effect on PT in the short term, mainly on pain reduction, but in the long term this effect disappears,[52] and results may be worse than with most conservative treatments.[53, 54]
Finally, surgery can be an option for treating PT, but results of studies investigating the effectiveness of surgery are also equivocal.[55-57] In general, it can be concluded that currently there is no definitive treatment for PT available.[49]

Aims of the thesis

The general objective of this thesis is to improve prevention and treatment of PT. The thesis has two aims. First, to increase knowledge about the etiology of PT. According to the TRIPP model, knowledge of risk factors is essential to develop preventive measures. A large number of risk factors have been suggested, but the literature seems dissimilar and inconclusive. For this reason, the literature on risk factors for PT will be reviewed and risk factors for PT in elite as well as non-elite basketball and volleyball players will be addressed.
ESWT is one of the treatment options for PT. Two types of shockwave devices are available at the moment: focused shockwave and radial shockwave devices. Most basic and clinical studies have used focused shockwave devices, but in the Netherlands radial shockwave devices are used more widely to treat PT.[58] Because of this discrepancy between science and practice, the second aim is to gain knowledge about ESWT as a treatment for PT, and more specifically about the differences between focused and radial ESWT.

Outline of the thesis

The first part of this thesis is about the etiology of PT. **Chapter 2** provides a systematic overview of the literature concerning risk factors for PT. **Chapter 3** reviews the literature that examines the relation between jumping biomechanics and PT. The following chapters exhibit the results of a cross-sectional survey concerning risk factors for PT among basketball and volleyball players (of all playing levels). **Chapter 4** describes demographic, anthropometric and sport-related risk factors, and **Chapter 5** occupational risk factors. This last chapter also describes the relation between PT and work limitations.

The topic of the second part of this thesis is the treatment of PT, with **Chapter 6** giving a practical overview of ESWT as a treatment for tendinopathy and **Chapter 7** presenting the design of a Randomized Controlled Trial (RCT) that compares the effectiveness of radial and focused ESWT. The results of this RCT are presented in **Chapter 8**.

This thesis ends with **Chapter 9**, which provides a general overview of this thesis and discusses findings as well as suggestions for future research.

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Chapter 2

Risk factors for patellar tendinopathy: A systematic review of the literature

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Abstract

Patellar tendinopathy is an injury with a high prevalence in sports. Knowledge of risk factors is essential for developing preventive measures and rehabilitation programs. However, risk factors associated with patellar tendinopathy have not yet been systematically studied. This review was undertaken to identify risk factors associated with patellar tendinopathy. The literature was systematically searched to identify articles that investigated risk factors for patellar tendinopathy. There was no strong or moderate evidence that any investigated risk factor was associated with patellar tendinopathy. For nine risk factors there was some evidence: weight, BMI, waist-to-hip ratio, leg-length difference, arch height of the foot, quadriceps flexibility, hamstring flexibility, quadriceps strength and vertical jump performance. Based on the present evidence, reducing body weight, increasing upper-leg flexibility and quadriceps strength and the use of orthotics may be beneficial treatment options. However, it should be stressed that the evidence for the nine identified risk factors was only limited. Therefore, there is a clear need for high-quality studies in order to identify the exact risk factors associated with patellar tendinopathy.

Introduction

Patellar tendinopathy (PT), or 'jumper's knee', is an injury that has a high prevalence in sports, especially those involving jumping, with reported prevalences of up to 45% and 32% in elite volleyball and basketball players respectively.[1] It is a painful chronic injury of the patellar tendon which interferes with many athletes' sports career and could even be the primary cause of ending it.[2] Because successful treatment of PT remains challenging, prevention is of the utmost importance. Knowledge of risk factors is essential for developing preventive measures.[3] However, factors associated with this injury have not yet been studied in a systematic way. The aim of this study was thus to review the literature and to identify risk factors associated with PT.

Methods

Search strategy and inclusion criteria

The Cochrane and MEDLINE databases were searched, revealing no systematic reviews about factors associated with PT. A search of the Pubmed, EMBASE and AMED databases was conducted to identify studies that met the inclusion criteria. The search was carried out from the earliest date to August 2010 using the following keywords (MeSH and/or text words): jumpers knee, jumper's knee, patella(r) tendinopathy, patella(r) tendinosis, patella(r) tendinitis, patella(r) tendonitis, patella(r) apicitis, patella(r) apex syndrome, patella(r) tip syndrome, patella(r) tenosynovitis, and plural forms. The search was restricted to articles in English. Abstracts, letters and reviews were excluded.

Studies were included in the systematic review if they contained: (1) empirical research that investigated factors associated with PT; and (2) a comparison between a group of patients and a group of controls. Studies focusing solely on biomechanics and radiology/ultrasonography were excluded. Of the studies included, factors that were measured radiographically or ultrasonographically were not taken into account. Three authors (HW, MA and JZ) independently screened titles and/or abstracts of the studies retrieved by the search strategy above. When no abstract was available, or when it was not clear if the study should be included, full-text articles were retrieved in order to determine inclusion or exclusion. Reference lists of included or other relevant articles (i.e. recent reviews) were checked for additional references.

Data extraction

Data on study population, study design, groups, diagnosis criteria and investigated factors was extracted and summarised from all the included studies. Investigated factors were divided into four categories: demographics, anthropometrics, sports-related factors and strength/flexibility.

Methodological quality assessment

Two reviewers (SR and IA) assessed the methodological quality of the studies by means of a methodological quality assessment list developed and used by Bongers et al. (2002),[4] which is based on a list developed by Van der Windt et al. (2000).[5] The list was slightly adapted to make it specific for PT, and contains items on information and validity and/or precision in five categories: *study objective*, *study population*, *outcome measurements*, *assessment of the outcome* and *analysis and data presentation*. Separate quality assessment lists were constructed for cross-sectional, case control and prospective cohort studies. The items of the adapted methodological quality assessment list are presented in table 1. Every item was scored as either "positive" ("+" for the item being met) or "negative" ("-" for the

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Search termes:
jumpers knee, jumper's knee, patella(r) tendinopathy, patella(r) tendinosis, patella(r) tendinitis, patella(r) tendonitis, patella(r) apicitis, patella(r) apex syndrome, patella(r) tip syndrome, patella(r) tenosynovitis

Pubmed Embase Amed (Ebsco)
↓ ↓ ↓
n = 430 n = 209 n = 44
↓
Total studies found
n = 683
↓
After checking for duplicates
n = 478
↓
After excluding letters/abstracts/reviews
n = 366
↓
After reading title/abstracts (full-text if necessary)
n = 9
↓
After reference checking
n = 11

Figure 1. Literature search

item not being met) by the two reviewers independently. When it was unclear whether a study did or didn't meet an item, or if no clear information regarding the item was stated, the item was scored "negative"(-). Results of these two quality assessments were compared, and any disagreement concerning an item was resolved in a consensus meeting. The total quality score of each study was calculated by counting the number of items that were scored positive on the validity/ precision items (items 3-16).

Strength-of-evidence assessment

Assessment of the strength of evidence for investigated factors was based on a method used by Ariëns et al. (2001).[6] Risk factors were classified into four levels of evidence:

- Strong evidence: consistent findings (which implies that at least 75% of the studies investigating a certain factor had to report an association) in multiple cohort and/or case-control studies with a high methodological quality score (above 50 on the methodological quality assessment list).
- Moderate evidence: consistent findings in multiple cohort and/or case-control studies, only one of which is a high-score study.
- Some evidence: findings of one cohort or case-control study, or consistent findings in multiple cross-sectional studies, at least one of which is a high-score study.
- Inconclusive evidence: concerns all other cases, including inconsistent findings.

Results

Identification of studies

No systematic reviews or randomised controlled trials could be found on this subject.

After checking for doubles the search of the computerised databases identified a total of 478 studies (figure 1). After excluding letters, abstracts and reviews, 366 studies were considered in the selection procedure. Based on the title, abstract and/or full papers, nine studies were included in the review.[7-15] After reference-checking two additional studies were included.[16, 17]

Description of studies

The 11 included studies consisted of six cross-sectional studies (CS),[10, 11-13, 16, 17] three case control studies (CC)[7, 14, 15] and one prospective cohort study (PC).[9] One study consisted of two parts, the first part with a cross-sectional design and the second with a case control design.[8] In seven of the 11 studies the subjects were volleyball or basketball players, with Malliaras et al. (2006) defining subjects as number of tendons.[8, 10-13, 16, 17] One study used runners as subjects,[15] two used athletes of different sports,[7, 14] and one used students following a physical education program as subjects.[9] Table 2 shows the study characteristics of the included studies.

Quality assessment

The scores of the studies on the methodological quality assessment list are presented in table 3. The average score was 41%.

Risk factors

Assessment of the strength of evidence is shown in table 4. Risk factors reported by a single study and not associated with PT in that study are not shown in this table.

Demographics

None of the demographic variables were a risk factor for PT according to the defined strength-of-evidence criteria. There was no association between age and PT in five studies that considered this variable.[8-10, 12, 16] Two studies assessed the link between gender and PT, and neither found differences between men and women in risk for PT.[14, 16] Gaida et al. (2004) found no differences in menstrual history (age of menarche, number of cycles in the last 12 months and use of oral contraceptives) between women with and without PT.[12]

Anthropometrics

There was some evidence that weight, BMI, waist-to-hip ratio, leg-length difference and arch height of the foot are risk factors for PT. None of the six studies that examined height found an association between height and PT.[8-12, 17] Three out of eight studies found an association between weight and PT.[10, 14, 17] In these studies subjects with PT were on average heavier than subjects without PT. The five other studies found no association between weight and PT.[7-9, 11, 12] Crossley et al. (2007) found that a higher BMI was associated with PT,[14] a finding that concurs with a study of Malliaras et al. (2007),[17] who also found an association between a higher BMI and PT, albeit only in men. Another study, that calculated a height-to-weight ratio, found no association between this ratio and PT.[7] Waist girth and hip girth

Table 1. Checklist for the Assessment of Methodological Quality of Cross-Sectional Studies (CS),Case-Control Studies (CC) and Prospective Cohort Studies (PC)

Study objective	
1. Positive, if the study had a clearly defined objective.	CS/CC/PC
Study population	
2. Positive, if the main features of the study population are described (sampling frame and distribution of the population according to age and sex).	CS/CC/PC
3. Positive, if cases and controls are drawn from the same population and a clear definition of cases and controls is given and if subjects with the disease/symptom in the past three months are excluded from the control group.	CC
4. Positive, if the participation rate is at least 80% or if the participation rate is 60-80% and the non-response is not selective (data shown).	CS/CC/PC
5. Positive, if the participation rate at main moment of follow-up is at least 80% or if the non-response is not selective (data shown).	PC
Outcome measurements	
6. Positive, if data on history of the disease/symptom is collected and included in the statistical analysis.	CS/CC/PC
7. Positive, if the outcome is measured in an identical manner among cases and controls.	CC
8. Positive, if the outcome assessments is blinded with respect to disease status.	CS/CC
9. Positive, if the outcome is assessed at a time prior to occurrence of the disease/symptom.	CC
Assessment of the outcome	
10. Positive, if the time period on which the assessment of disease/symptom was based was at least 1 year.	PC
11. Method for assessing injury status: physical examination blinded to exposure status (+); self-reported: specific questions relating tosymptoms/disease/use of manikin (+), single question (-).	CS/CC/PC
12. Positive, if incident cases were included (prospective enrollment).	CC
Analysis and data presentation	
13. Positive, if the measures of association estimated were presented (OR/RR), including confidence intervals and numbers in the analysis.	CS/PC/CC
14. Positive, if the analysis is controlled for confounding or effect modification: individual factors.	CS/PC/CC
15. Positive, if the analysis is controlled for confounding or effect modification: other factors.	CS/PC/CC
16. Positive, if the number of cases in the final multivariate model was at least ten times the number of independent variables in the analysis.	CS/PC/CC

were associated with PT in men in one study (hip girth only in men with bilateral PT),[17] but not in another study that only included women.[12] A higher waist-to-hip ratio, the combination of these two variables, was associated with PT in women with unilateral PT[12] and in men with bilateral PT.[17] No difference was found in skin

Table 2. Characteristics of included studies

Author (year)	Study design	Population	N	Groups (n, mean age±SD, f:m)	Factors investigated (bold are significant), Demographics	Anthropometrics	Sports-related factors	Strength/Flexibility
Cook et al. (2004)[11]	CS	Junior (ages 14-18) elite basketball players (m/f)	135	*Female (64, NA)* UL abnormality (8, NA) BL abnormality (8, NA) CON (48, NA) *Male (71, NA)* UL abnormality (17, NA) BL abnormality (16, NA) CON (38, NA)		height, weight, skinfolds, arm span/ height		**sit and reach *(m: BL vs.CON)/f: UL vs. CON)***, agility, speed, endurance, **vertical jump height *(f)***
Crossley et al. (2007) [14]	CC	Participants in competitive basketball, netball, volleyball, soccer or tennis (m/f)	58	UL PT (14, 26±7, 4:10) BL PT (13, 28±8, 4:9) CON (31, 24±6, 11:20)	sex	**weight**, **BMI**, **arch height during maximal weight bearing, leg-length difference**	**sport hours/wk *(BL vs. CON)***	sit-and-reach test, ankle flexibility, **active knee extension *(BL vs. CON)***, **normalised peak knee extensor moment *(UL vs.CON)***, calf endurance, hop test
Ferretti et al. (1984)[16]	CS	Competitive volleyball players (m/f)	407	PT (93, NA, 19:74) CON (314, NA, NA)	age, sex		years of play, **frequency of play, playing surface**, strength training	
Gaida et al. (2004)[12]	CS	Elite basketball players (f)	39	UL PT (8, 20±2) BL PT (7, 21±3) CON (24, 21±3)	age, menstrual history	height, weight**, tibial length to stature ratio *(UL vs. CON)*, waist-to-hip ratio *(UL vs.CON)***	**training hours/wk** (**last 6 months**)	sit-and-reach test, concentric strength, eccentric strength, jump height
Krauss et al. (2007)[15]	CC	Runners (f)	46	PT (20, 37.6±8.9) CON (26, 39.9±5.7)			training-specific data	maximum concentric and eccentric peak torque (60º/s), relative peak torques, concentric hamstring-quadriceps-quotient (HQQ), eccentric quotient (EQ)

Table 2. Continued

Author (year)	Study design	Population	N	Groups (n, mean age±SD, f:m)	Factors investigated (bold are significant), Demographics	Anthropometrics	Sports-related factors	Strength/Flexibility
Kujala et al. (1986)[7]	CC	Competitive players of volleyball, running, orienteering, basketball or other sports (m)	40	Patellar apicitis (=PT) (20, 27.4±6.4) CON (20, 27.6±6.0)		weight, height-to-weight ratio, **leg-length inequality**, knee laxity, Q-angle displacement, maximal knee hyperextension		flexion torque, extension torque
Lian et al. (1996)[8]	CS	Division I and II volleyball players (m)	141	1) With PT (55, 24.8±4.2) Without PT (86, 24.6±4.6)	age	1) height, weight	number of seasons played, **number of volleyball training sessions/wk,** strength training, jump training, warming up, stretching	
	CC		24	2) (subgroup) Patients (12, 23.7±3.0) CON (12, 24.8±4.6)				2) **jump performance**
Lian et al. (2003)[10]	CS	Division I volleyball players (m)	44	PT (24, 22.4±5.5) CON (20, 22.0±4.0)	age	height, **weight**	years of volleyball, training hours/wk, jump training, stretching, **strength training**	**jump performance**
Malliaras et al. (2006)[13]	CS	Competitive volleyball players (m/f)	190	Imaging tendon abnormality without pain (50, NA, NA) Imaging tendon abnormality with pain (53, NA, NA) Controls (87, NA, NA)			years of volleyball, weekly activity	**ankle dorsiflexion range**, sit-and-reach test, jump height, ankle flexion strength

f = female; **m** = male; **PT**= patellar tendinopathy/tendinitis; **CON** = controls; **UL** = unilateral; **BL** = bilateral; **CC** = case-control study; **CS** = cross-sectional study; **PC** = prospective cohort study; **BMI=** body mass index; **VISA =** questionnaire developed for patients with patellar tendinopathy: assesses severity of symptoms, function and ability to participate in sports; **NA=** not available folds between subjects with and without PT.[11] Several studies investigated the association between leg-length difference and PT. Crossley et al. (2007) found the leg-length difference to be bigger in subjects with PT compared to controls, the symptomatic leg on average being the longer one.[14] Kujala et al. (1986) also reported a larger leg-length difference in subjects with PT.[7] The study of Witvrouw et al. (2001) however found no association with leg-length difference.[9] A longer tibia length relative to stature was found by Gaida et al. (2004) in subjects with unilateral PT.[12] Kujala et al. (1986) found no difference between controls and subjects with PT in Q-angle displacement during knee flexion.[7] In another study there was no difference in Q-angle at rest between these two groups either, and no difference in medial tibial intercondylar distance.[9] Arch height of the foot differed between subjects with and without PT.[14] Subjects with PT had a lower foot arch height. One study that investigated arm span to height ratio found no association between this ratio and PT.[11]

Sports-related factors

None of the sports-related factors were identified as risk factors for PT. Two studies found no difference in number of years playing between volleyball players with and without symptoms.[10, 13] Three studies found amount of training and playing to be a significant risk factor for PT.[8, 12, 16] Three other studies found no association between amount of training and competition and PT in volleyball players[10, 13] and in runners.[15] Strength training was not associated with PT in two studies,[8, 16] whereas in another study (where more strength training was associated with PT) it was.[10] Two studies found no association between amount of jump training and PT.[8, 10] Ferretti et al. (1984) showed that incidence of PT is higher in players who play on concrete compared to those who play on parquet or linoleum.[16] Kraus et al. (2007) found no difference in percentages of running on hard surfaces between injured subjects and healthy controls.[15] No differences were found for warm-up time and stretching time,[8] or for stretching time during warm-up and after training.[10]

Strength/flexibility

Of the strength/flexibility variables quadriceps flexibility, hamstring flexibility, quadriceps strength and vertical jump performance were factors for which there was some evidence according to the defined strength-of-evidence criteria. Witvrouw et al. (2001) found differences in flexibility between subjects with PT and controls.[9] Controls had a higher quadriceps and hamstring flexibility compared

Table 3. Scores on the Items of the Quality Assessment List (see Table 1), with the Total Quality Score for all Positive Validity/ Precision Items (3-16) and the Percentage of the Maximum Attainable Score (%)

Reference		***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***Total***	***%***
Witvrouw et al. (2001)[9]		+	+		+	+	-				+	+		-	+	+	+	7/9	78
Malliaras et al. (2007)[17]		+	+		-		-		+			+		+	+	+	+	5/8	63
Crossley et al. (2007)[14]		+	+	+	-		-	+	-	-		+	-	-	+	-	+	5/12	42
Lian et al. (1996)[8]	2)	+	+	+	-		-	+	-	-		+	-	-	+	+	-	5/12	42
Lian et al. (2003)[10]		+	+		+		-		-			+		-	+	-	-	3/8	38
Cook et al. (2004)[11]		+	+		-		-		+			+		-	+	-	-	3/8	38
Malliaras et al. (2006)[13]		+	+		-		-		+			+		+	-	-	-	3/8	38
Gaida et al.(2004)[12]		+	+		-		-		+			+		-	+	-	-	3/8	38
Krauss et al.(2007)[15]		+	+	-	+		-	+	-	-		+	-	-	+	-	-	4/12	33
Kujala et al. (1986)[7]		+	+	-	-		-	+	-	-		+	-	-	+	-	-	3/12	25
Lian et al. (1996)[8]	1)	+	+		+		-		-			+		-	-	-	-	2/8	25
Ferretti et al. (1984)[16]		+	-		+		-		-			+		-	-	-	-	2/8	25

Table 4. Strength of evidence for relationship between associated factors and PT.

Risk factor	Number of high- and low-score studies	Number of studies with positive effect	Level of evidence
Demographics			
Age	High: 1 Low: 4	High: 0 Low: 0	inconclusive
Gender	High: 0 Low: 2	High: 0 Low: 0	inconclusive
Anthropometrics			
Height	High: 2 Low: 4	High: 0 Low: 0	inconclusive
Weight	High: 2 Low: 6	High: 1 Low: 2	some
BMI/weight-height ratio	High: 1 Low: 2	High: 1 Low: 1	some
Waist and hip girth	High: 1 Low: 1	High: 1 Low: 0	inconclusive
Waist-to-hip ratio	High: 1 Low: 1	High: 1 Low: 1	some
Leg-length difference	High: 1 Low: 2	High: 0 Low: 2	some
Longer tibial length to stature	High: 0 Low: 1	High: 0 Low: 1	inconclusive
Arch height of foot	High: 0 Low: 1	High: 0 Low: 1	some
Sports-related factors			
Playing years	High: 0 Low: 2	High: 0 Low: 0	inconclusive
Amount of training/competition	High: 0 Low: 6	High: 0 Low: 3	inconclusive
Strength training	High: 0 Low: 3	High: 0 Low: 1	inconclusive
Jump training	High: 0 Low: 2	High: 0 Low: 0	inconclusive
Playing surface volleyball	High: 0 Low: 1	High: 0 Low: 1	inconclusive
Strength/flexibility			
Quadriceps flexibility	High: 1 Low: 0	High: 1 Low: 0	some
Hamstring flexibility	High: 1 Low: 1	High: 1 Low: 0	some
Sit and reach scores	High: 0 Low: 4	High: 0 Low: 1	inconclusive
Angle dorsiflexion range	High: 0 Low: 2	High: 0 Low: 1	inconclusive
Quadriceps strength	High: 1 Low: 4	High: 0 Low: 1	some
Hamstring strength	High: 1 Low: 1	High: 0 Low: 0	inconclusive
Vertical jump performance	High: 0 Low: 5	High: 0 Low: 3	some

to subjects with PT. No differences were found in hamstring flexibility in another study.[14] Four studies looked at differences in sit- and reach scores, which is a measure of hamstring and low back flexibility. Cook et al. (2004) found differences in sit and reach scores between subjects with unilateral PT and controls in women and between subjects with bilateral PT and controls in men.[11] These groups had lower sit and reach scores than controls. Gaida et al. (2004), Malliaras et al. (2006) and Crossley et al. (2007) found no differences in scores on a sit and reach test.[12-14] Ankle dorsiflexion range was found to be smaller in subjects with PT in one study,[13] but not in another.[14] Crossley et al. (2007) reported that normalised peak knee extensor moment was lower in subjects with unilateral PT compared to controls, but not for bilateral PT.[14] Other studies found no differences in knee flexion and extension torques,[7] concentric and eccentric strength,[12] hamstring and quadriceps strength,[9] or ankle plantar flexion strength[13] between groups. No differences between groups were found in calf endurance,[14] speed, endurance and agility,[11] and hamstring-quadriceps-quotient (HQQ), which describes the imbalance between knee flexors and extensors.[15] Cook et al. (2004) found that women with PT jumped higher than women without PT, but they found no differences in men.[11] A better performance on jump tasks of subjects with PT was also shown by other studies.[8, 10] Gaida et al. (2004) and Malliaras et al. (2006) however found no differences in jump height.[12, 13] Crossley et al. (2007) found no differences on a speed hop test and a distance hop test.[14]

Discussion

The aim of this study was to review the literature concerning risk factors associated with PT. The number of included studies was low and the studies were heterogeneous in investigated factors: over 40 potential risk factors were investigated, therefore conducting a meta-analysis was impossible.

Although a number of risk factors are considered to be related to PT, no strong or moderate evidence could be obtained for any of the investigated factors. For nine factors there was some evidence for an association with PT: weight, BMI, waist-to-hip ratio, leg length difference, arch height of the foot, quadriceps flexibility, hamstring flexibility, quadriceps strength and vertical jump performance. For all the other investigated factors the evidence was inconclusive.

Although the exact pathophysiology of tendinopathy is unclear, several theories have been developed,[18] the main one being the mechanical theory. According to this theory, because of a failed healing process, micro injuries in the tendon resulting from overload can eventually lead to matrix and cell changes as well as altered mechanical properties of the tendon. All nine identified risk factors influence the loading of the patellar tendon in some way, and could be explained within the framework of mechanical pathophysiological theory.

The apparent association of weight and BMI with PT can be explained by a higher body mass theoretically leading to a higher loading of the patellar tendon, which increases chances of overload. A higher waist-to-hip ratio was also associated with PT and indicates a higher abdominal fat distribution compared to gluteofemoral fat distribution. The effect of a higher waist-to-hip ratio may be purely mechanical, as in the case of weight. However, the effect may also be non-mechanical. Fat distribution is controlled by a number of hormones (such as estrogen and progesterone). Because of the higher waist-to-hip ratio in subjects with PT, it has been suggested that hormones playing a role in fat distribution may also play a role in tendinopathy.[12, 17] Another non-mechanical explanation for the higher waist-to-hip ratio in subjects with PT is that an increase of free fatty acids and pro-inflammatory cytokines resulting from elevated abdominal adiposity may negatively influence tendon health.[17, 19]

The possible association between leg-length difference and PT may be caused by the fact that the longer leg is the preferred take-off leg in jumping more often, as suggested by Kujala et al. (1986).[7] Crossley et al. (2007) state that the found leg-length differences in their study are too small to be considered functionally important.[14] The differences found by Kujala et al. (1986) are even smaller. Hence although there is some evidence that leg-length difference is related to PT, whether this link is clinically relevant remains a question.

A lower arch height of the foot in subjects with PT concurs with a study by Williams et al. (2001), who found low-arched runners were more likely to develop knee and soft tissue injuries than high-arched runners, who were more likely to develop ankle and bone injuries.[20] They found a greater peak knee flexion angle in runners with a low foot arch, and postulate that greater quadriceps muscle force is needed to prevent further knee flexion. One can hypothesise that something similar happens during jumping.

Quadriceps and hamstring flexibility may be associated with PT because decreased flexibility increases tendon strain during joint movements and may therefore lead to tendon overload,[9] which is in line with the mechanical theory.

Lower quadriceps strength may be caused by atrophy as a result of inactivity brought about by PT, yet it may also be the cause of PT. Longitudinal studies are needed to determine the causal relation.

There was some evidence that vertical jump performance was better in subjects with PT, which contrasts with the mentioned lower quadriceps strength. This may have two reasons. First, although jump performance and quadriceps strength are related factors, there is more to jump performance than quadriceps strength alone. Second, for both factors only some evidence for an association with PT exists, leaving the possibility of an association for only one of those two factors. Further research into these factors is required.

There may be several reasons for not finding strong or moderate evidence for any of the investigated factors. First, the number of studies was low, as was their overall methodological quality. Furthermore — and this may be related to the former — results were often conflicting. Also, most studies used univariate statistical techniques to test for differences between groups, often even without correction for multiple testing. Using more sophisticated statistical procedures like multiple logistic regression helps to identify risk factors while accounting for other pertinent variables. Finally, PT is likely to have a multifactorial etiology, therefore identifying risk factors may be more difficult.

The nine identified risk factors could potentially be relevant for prevention and rehabilitation. With the present evidence, reducing weight (which is associated with BMI and waist-to-hip ratio) may be a beneficial intervention in the case of overweight. According to Kountouris & Cook (2007),[21] addressing dysfunctions in the muscle/tendon complex and in the pelvic and lower limb kinetic chain are an important part of tendinopathy rehabilitation; the present study suggests that upper-leg flexibility and quadriceps strength may be important factors to focus on in such an approach. They also suggest that foot arch height may be addressed by orthotics to influence lower-limb absorbing function; this may also be an option for leg-length differences. However, when applying the present findings for prevention and rehabilitation purposes one should keep in mind that the evidence for the nine identified risk factors was limited.

A limitation of the review is that when studies were assessed for strength of evidence, results were not split for each subgroup. A positive association for a subgroup (e.g. subjects with unilateral PT) was taken as a positive association for the whole study. This was done because evidence for most investigated factors was scarce and a splitting into subgroups makes it even harder to identify risk factors. The evidence for differences between men and women and between bilateral and unilateral tendinopathy is also limited.

Further research into risk factors for PT is required, since no strong or moderate evidence was found for an association between PT and any of the investigated factors. Future research should at least include the nine variables for which some evidence was found. Ideally, these studies should be prospective and use multivariate statistical techniques. Most studies in this review used elite-level athletes, therefore future research should also include recreational athletes to make results more generalizable.

Conclusion

We studied risk factors for PT that have been described in the literature. The number and overall methodological quality of the included studies was low. The etiology of PT seems to be multifactorial. Nine factors — weight, BMI, waist-to-hip ratio, leg-length difference, arch height of the foot, quadriceps flexibility, hamstring flexibility, quadriceps strength and vertical jump performance — were identified as possible risk factors for PT, although there was only some evidence. There is a clear need for high-quality studies that are prospective and longitudinal and which use more sophisticated statistical methods in order to identify the exact risk factors associated with PT.

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Chapter 3

Is the jumper's knee a lander's knee? A systematic review of the relation between take-off and landing biomechanics and patellar tendinopathy

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Abstract

Patellar tendinopathy (jumper's knee) is a common injury in sports that comprise jump actions. This article systematically reviews the literature that examines the relation between patellar tendinopathy and take-off and landing biomechanics, in order to uncover risk factors and potential prevention strategies. A systematic search of the Pubmed, Embase and Amed databases was conducted, and nine articles that met the inclusion criteria were identified. The identified studies were diverse in methods used, jump actions studied and in populations. A synthesis of the literature suggests that a flexible movement pattern during jumping reduces the risk for patellar tendinopathy and that patellar tendinopathy is related to landing more so than take-off. Accordingly, employing a flexible movement pattern, especially during landing, seems an expedient strategy to reduce the risk for developing/redeveloping patellar tendinopathy. Together, these findings indicate that improving kinetic chain functioning, performing eccentric exercises and changing landing patterns are potential tools for preventive and/or therapeutic purposes.

Introduction

Patellar tendinopathy (PT), also known as jumper's knee,[1] is a common injury in sports that involve repetitive jumping like basketball and volleyball. Among elite and recreational basketball players the prevalence is 32% and 12% respectively, and among elite and recreational volleyball players 45% and 14% respectively.[2, 3] Prevention of this injury is important because symptoms can last for years, can affect sports and work participation, and can even be a reason to end a sports career.[4, 5] Although several treatments have been described, treatment results are variable.[6] Knowledge of risk factors is necessary in order to develop preventive measures.[7] Many risk factors have been suggested in the literature and it appears that PT has a multifactorial etiology. Suggested factors for which there is most evidence that they play a role in the onset of PT are weight, body mass index, waist-to-hip ratio, leg-length difference, arch height of the foot, quadriceps flexibility, hamstring flexibility, quadriceps strength, vertical jump performance and training volume.[8, 9] The high prevalence of PT in sports that involve jump actions suggests that PT is caused by jumping – that is, by take-off and/or landing. Hence to understand the etiology of PT one must at least understand the relation between PT and take-off and landing. Indeed, a number of biomechanical studies have investigated how take-off and landing may be related to PT. However, as we will see in the current review, these studies are diverse in their adopted research methods, jump actions studied, and populations. Furthermore, the causality in the relation between jump biomechanics and PT is often ambiguous. The aim of this systematic review is to come to a better understanding of how PT may be related to take-off and landing biomechanics. Studying both jump phases may provide more insight into the development of PT, and also addresses the question of whether take-off and landing pose an equal risk for developing PT. In this way risk factors may be uncovered which can be used to identify take-off and/or landing patterns which predispose athletes for developing PT. Potential means for prevention of PT can be subsequently developed through, for example, adaptation/training of these patterns.

Methods

Search strategy and inclusion criteria

A computerised search of the Pubmed, Embase and Amed databases was conducted in October 2011. The following terms were used: *patella(r) tendon, jumpers knee, jumper's knee, patella(r) tendinopathy, patella(r) tendinosis, patella(r) tendinitis, patella(r) tendonitis, patella(r) apicitis, patella(r) apex syndrome, patella(r)*

Search terms:

patella(r) tendon, jumpers knee, jumper's knee, patella(r) tendinopathy, patella(r) tendinosis, patella(r) tendinitis, patella(r) tendonitis, patella(r) apicitis, patella(r) apex syndrome, patella(r) tip syndrome, patella(r) tenosynovitis AND jump, jumping, land, landing, take off, touchdown

	Pubmed	Amed	Embase
	↓	↓	↓
Studies identified	73	11	42
	↓		
Total studies identified	126		
	↓		
After checking for duplicates	97		
	↓		
After excluding reviews/letters/abstracts	80		
	↓		
After reading articles	8		
	↓		
After reference checking	9		

Figure 1. Literature search

tip syndrome, patella(r) tenosynovitis combined with *jump, jumping, land, landing, take off, touchdown* and plural forms. The search was restricted to articles in English. Reference lists of the included studies as well as other relevant studies were checked for additional references. Studies were included if they met the following three criteria: 1) it was an empirical study that investigated jump and landing characteristics of real jumps in relation to PT; 2) kinematics, kinetics or energetics of these jumps were collected; and 3) a comparison was made in that study between a control group and a group with (a)symptomatic PT. Titles and abstracts were screened independently by two authors to determine inclusion or exclusion. If it was not clear whether the study should be included, the full text was screened.

Data extraction

Data on study population, investigated factors and jump tasks were extracted and summarised from the included studies. Investigated factors were categorised into *kinematics*, *kinetics* and *energetics*.

Table 1. Characteristics of included studies

Author (year)	Factors	Analysed jump phase	Jump action	Population	N	Groups (N)
Lafortune (1985)	Kinematics (Hip, Knee)	TL	Vertical jump	Male college basketball players	7	control (5) previous PT (asymptomatic) (2)
Richards et al. (1996)	Kinematics and kinetics (Knee)	TL	Block jump and spike jump	Men of the Canadian National volleyball team	10	control (7) symptomatic PT (3)
Richards et al. (2002)	Kinematics and kinetics (Ankle)	TL	Spike jump	Men of the Canadian National volleyball team	10	control (7) symptomatic PT (3)
Bisseling et al. (2007)	Kinematics, kinetics and energetics (Hip, Knee, Ankle)	L	Drop jump landings from 30, 50 and 70 cm height	Male elite volleyball players	24	control (8) previous PT (asymptomatic) (7) symptomatic PT (9)
Bisseling et al. (2008)	Kinematics, kinetics and energetics (Knee, Ankle)	TL	Spike jump	Male elite volleyball players	15	control (8) previous PT (asymptomatic) (7)
Siegmund et al. (2008)	Kinematics (Hip, Knee, Ankle)	TL	Standing countermovement jumps, running layup jumps	Male basketball players, elite and recreational	24	control (12) symptomatic PT (12)
Edwards et al. (2010)	Kinematics, kinetics and EMG (Hip, Knee, Ankle)	L	Stop jump	Male athletes from team sports involving repetitive landing	23	controls (16) PTA, no previous or current symptoms (7)
Sorenson et al. (2010)	Kinematics, kinetics and energetics (Knee)	T	Spike jump	Male elite volleyball players	13	controls (7) PT without self-reported activity limitations (6)
Souza et al. (2010)	Kinetics (Hip, Knee, Ankle)	TL	Hopping	Male elite volleyball players	14	controls (7) PT without self-reported activity limitations (7)

L = landing phase; T = take-off phase

Results

Results of literature search

Nine articles that investigated the relation between patellar tendinopathy and jumping biomechanics were included in the review (figure 1). The literature search yielded 8 articles,[10-17] and one additional study was found after reference-checking.[18]

Description of studies

Characteristics of the included studies are shown in Table 1. Five studies compared subjects with clinically diagnosed symptomatic PT with a control group.[10, 11, 14, 16, 17] The study by Bisseling et al. (2007) compared a group of controls with an asymptomatic group with previous PT and a symptomatic group with current PT.[12] The same authors conducted another study with only the first two groups.[13] This last comparison was also made in another study.[18] Edwards et al. included subjects without present or previous symptoms, but with patellar tendon ultrasonographic abnormality (PTA), and compared them with subjects without ultrasonographic abnormalities.[15] The presence of PTA increases the likelihood of the onset of PT.[19-21] Studying a group with PTA provides an opportunity to study subjects without symptoms but with a high risk for developing PT. In the remainder of this article, the term 'asymptomatic' refers to both subjects with PTA and subjects with previous PT.

Jump tasks investigated were a vertical jump task,[18] the volleyball spike jump,[10, 11, 13, 16] the volleyball block jump,[10] a drop jump,[12] a standing countermovement jump,[14] a running layup jump,[14] a stop jump task,[15] and hopping.[17] Six of the nine studies looked at take-off and landing,[10, 11, 13, 14, 17, 18] two only analysed the landing,[12, 15] and one study solely examined the take-off.[16] So both jump phases are represented fairly evenly in the included studies.

Methodological quality of the studies

No prospective studies were found during the search; all included studies had a cross-sectional design. Drawing conclusions about causality is therefore impossible. Three studies reported that the subject characteristics (e.g. age, height, weight) of the control group and the (a)symptomatic group were comparable,[15-17] one study reported that groups were matched (on height, weight, position, experience and frequency of play) but did not support this with statistical testing,[14] and the five remaining studies made no statements about the comparability of groups.

Table 2. Differences in jump kinematics between controls and other study groups

	Variable	Reference	Analysed jump phase	Task	Groups (compared to controls)		
					PT-S	PT-P	PTA
Ankle	Ankle flexion at maximal VGRF	[12]	L	Drop jump	<		
	Ankle flexion at TD	[13]	L	Spike jump		<	
	Maximum dorsiflexion angle	[14]	L	Layup jump	<		
	Ankle inversion at maximal PTF	[15]	L	Stop-jump vertical phase			>
Knee	Knee ROM	[18]	L	Vertical jump		<	
	Knee ROM	[10]	L	Spike jump	>		
	Knee ROM	[13]	L	Spike jump		<	
	Knee ROM	[15]	L	Stop-jump horizontal phase			<
	Knee flexion at TD	[15]	L	Stop-jump horizontal phase			>
	Knee flexion velocity at TD	[15]	L	Stop-jump horizontal phase			<
	Knee angular velocity	[12]	L	Drop jump		>[1]	
	Maximum knee flexion acceleration	[14]	L	Standing counter movement jump	<		
	Time to maximum knee flexion	[14]	T	Standing countermovement jump	>		
	Internal knee rotation	[15]	L	Stop-jump horizontal phase			>
Hip	Hip ROM	[18]	L	Vertical jump		<	
	Hip extension velocity at TD	[15]	L	Stop-jump horizontal phase			>
	Hip abduction at maximal VGRF	[15]	L	Stop-jump horizontal phase			>
	Hip external rotation velocity at maximal patellar tendon force	[15]	L	Stop-jump horizontal phase			>
	Hip flexion velocity at maximal VGRF	[15]	L	Stop-jump vertical phase			>
	Maximum hip flexion angle	[14]	T	Standing countermovement jump	>		
	Maximum hip flexion acceleration	[14]	T	Standing countermovement jump	<		
Interaction	Between knee and ankle ROM	[13]	L	Spike jump		<	
	Between knee angular velocity during eccentric phase of take-off and landing	[13]	TL	Spike jump		>	

1 = compared to PT symptomatic; > = a higher value than controls; < = a lower value than controls; **L** = landing phase; **PTA** = patellar tendon ultrasonographic abnormalities; **PTF** = patellar tendon force; **PT-P** = previous patellar tendinopathy; **PT-S** = symptomatic patellar tendinopathy; **ROM** = range of motion; **T** = take-off phase; **TD** = touchdown; **VGRF** = vertical ground reaction force

Table 3. Differences in jump kinetics between controls and other study groups.

	Variable	Reference	Analysed jump phase	Task	Groups (compared to controls)		
					PT-S	PT-P	PTA
General	Maximal VGRF	[10]	T	Spike jump	>		
		[16]	T	Spike jump	<		
	Maximal VGRF	[10]	T	Block jump	>		
	Loading rate VGRF	[10]	T	Spike jump	>		
	Loading rate VGRF	[12]	L	Drop jump		>	
	Loading rate VGRF	[15]	L	Stop-jump vertical phase			<
Ankle	Right foot inversion moment (in right knee PT)	[11]	L	Spike jump	>		
	Loading rate ankle moment	[12]	L	Drop jump	<	>	
Knee	Peak loading rate knee extensor moment	[10]	L	Spike jump	>		
	Peak tibial external rotation moment	[10]	T	Spike jump	>		
	Peak tibial external rotation moment	[10]	T	Block jump	>		
	Peak knee moment	[12]	L	Drop jump	<		
	Loading rate knee moment	[12]	L	Drop jump		>[1]	
	Loading rate knee moment (eccentric phase)	[13]	T	Spike jump		>	
	Knee contribution to total support moment	[17]	TL	Hopping	<		
Hip	Hip contribution to total support moment	[17]	TL	Hopping	>		

1 loading rate was significantly higher than the symptomatic group, with trend towards being significantly higher than the control group
> = a higher value than controls; < = a lower value than controls; **L** = landing phase; **PT** = patellar tendinopathy; **PTA** = patellar tendon ultrasonographic abnormalities; **PT-P** = previous patellar tendinopathy; **PT-S** = symptomatic patellar tendinopathy; **ROM** = range of motion; **T** = take-off phase; **VGRF** = vertical ground reaction force

Table 4. Differences in jump energetics between controls and other study groups.

Variable	Reference	Analysed jump phase	Task	Groups (compared to controls)		
				PT-S	PT-P	PTA
Peak knee power	[12]	L	Drop jump	<		
Knee joint work	[12]	L	Drop jump	<		
Knee net joint work (eccentric phase)	[16]	T	Spike jump	<		
Positive-to-negative knee net joint work ratio	[16]	T	Spike jump	>		
Average knee net joint power (eccentric phase)	[16]	T	Spike jump	<		
Positive-to-negative average knee net joint power	[16]	T	Spike jump	>		

> = a higher value than controls; < = a lower value than controls; **L** = landing phase; **PTA** = patellar tendon ultrasonographic abnormalities; **PT-P** = previous patellar tendinopathy; **PT-S** = symptomatic patellar tendinopathy; **T** = take-off phase

For these five studies it is possible that differences between study groups are not the result of the presence or absence of PT, but are related to other variables that differed between groups.

Jump biomechanics

Differences between groups for take-off and landing were found for a number of kinematic (Table 2), kinetic (Table 3) and energetic (Table 4) variables. Although take-off and landing were investigated by almost the same number of studies (7 vs. 8), differences between groups, which are possible risk factors, were found more often for the landing (see Tables 2-4).

Kinematics

Take-off

Symptomatic subjects showed greater maximal hip flexion, lower angular accelerations for hip and knee flexion, and a longer time to maximal knee flexion compared to controls.[14]

Landing

Symptomatic subjects showed more range of motion (ROM),[10] and lower angular velocities for the knee during landing.[14] It was also found that symptomatic subjects have a smaller maximal ankle dorsiflexion angle than controls.[14] Compared to controls, subjects with previous PT and PTA showed smaller ankle plantar flexion at touchdown (TD) and larger knee angle at TD,[13, 15] smaller ROM for knee and hip,[13, 15, 18] and greater angular velocities in the hip.[15] They also showed differences for kinematics in the frontal and axial planes, such as more ankle inversion, internal knee rotation and hip abduction and greater hip external rotation velocity.[15]

Differences between groups

Symptomatic subjects generally showed a flexible movement pattern with more joint flexion and took more time for their take-off and landings, except for the finding that they have a smaller maximal ankle dorsiflexion angle than controls during landing. Subjects with asymptomatic PT, on the other hand, showed a stiff jump and landing pattern, opposite to that of symptomatic PT subjects – that is, with less joint flexion and higher velocities during take-off and landing. They also showed more translation in the frontal and axial planes.

Kinetics

Take-off

One study found a higher maximal vertical ground reaction force (VGRF) and loading rate of the VGRF for symptomatic subjects compared to controls for the spike jump take-off and only a higher vertical ground reaction force (VGRF) for the block jump take-off,[10] whereas another found that the maximal VGRF was lower for the spike jump take-off in symptomatic subjects compared to controls.[16] The loading rate of the knee moment during spike jump take-off was higher in subjects with previous PT compared to controls.[13] Richards et al. (1996) showed that the tibial external rotation moment was higher in symptomatic subjects compared to controls during both block jump and spike jump take-off.[10]

Landing

The inversion moment of the foot was higher in symptomatic subjects compared to controls.[10,11] For moments in the sagittal plane it was found that the peak knee moment was lower in symptomatic subjects than in controls (drop jump landing),[12] whereas the peak loading rate of the knee moment was higher (spike jump landing),[10] and the knee contributed less to the total support moment.[17] Subjects with previous PT showed higher loading rates of VGRF and knee and ankle moments than controls,[12] whereas the only study that compared subjects with PTA with controls found that the loading rate of the VGRF was lower in the first group.[15]

Differences between groups

The observed differences in kinetics between groups were inconsistent across studies. The only clear difference was that for moments in the transverse plane which were higher in symptomatic subjects than in controls.

Energetics

Take-off

Differences in energetics were found between controls and symptomatic subjects during spike jump take-off, with symptomatic subjects showing less knee net joint work and average knee net joint power than controls.[16] Symptomatic subjects also showed a higher positive-to-negative ratio of knee net joint work and knee net joint power during this action.[16]

Landing

During landing of a drop jump symptomatic subjects also had lower knee power and knee joint work than controls.[12]

Differences between groups

Overall, symptomatic subjects generated less energy than controls, especially during eccentric movements in take-off and landing.

Discussion

The aim of this systematic review was to come to a better understanding of how PT may be related to take-off and landing biomechanics. The review revealed a number of differences in kinematics, kinetics and energetics between subjects with (a)symptomatic PT and controls. Some of these differences may play a role in the onset of PT, whereas others may be the result of PT. As no prospective studies are available in the literature it is impossible to discern causes and effects. These results as currently available from literature do not allow for firm conclusions regarding causality in the relation between these differences in jump biomechanics and PT. Furthermore, because of the heterogeneity of the studies the results were difficult to cluster, hence a direct comparison between studies is unfeasible. This heterogeneity resided in the diversity of the adopted methods, the employed jump actions and the studied populations.

The joints together with the bones, muscles and tendons form a kinetic chain. During take-off this kinetic chain acts to overcome gravity in order to propel the body into the air, while during landing this kinetic chain acts to dissipate kinetic energy, by muscles and tendons, to withstand collapsing. Both take-off and landing are achieved by interplay between the components of the kinetic chain, and the role of each component can vary. For example, a stiff landing will put more load on the skeletal system, whereas a flexible landing (with greater flexion angles) will put more load on the muscles.[23] As we will argue, kinetic chain function plays an important role in developing PT.

Based on the kinematics of subjects with symptomatic PT it can be hypothesised that they used a tendon load-avoiding movement pattern to minimise pain, a pattern characterised by greater maximal flexion, greater ROM and lower velocities.[12] Devita and Skelly (1992) found that a flexible (soft) landing pattern, with large maximum knee flexion angles, led to an increased absorption of kinetic energy by the muscles, thereby putting less stress on the other tissues.[23] Compared to subjects with symptomatic PT, subjects with previous PT and PTA generally showed a less flexible (i.e. stiff (Devita & Skelly 1992)) jumping and landing pattern with smaller ROM and greater angular velocities. Such kinematics indicate that subjects with previous PT likely revert to a pattern that caused their PT in the past now that the pain has disappeared. Because PTA is thought to be a precursor of symptomatic PT,[19-21] subjects with PTA constitute a high-risk population for developing PT and are likely to show riskful jump biomechanics. Hence despite the absence of prospective studies, from studies examining asymptomatic groups (i.e. subjects with previous PT and subjects with PTA) we may hypothesise that whereas the symptomatic group used a flexible movement pattern to minimize pain, subjects with previous PT and PTA show a stiff pattern that puts them at risk for developing or re-developing PT. The results regarding the kinetics could be interpreted less straightforwardly than the kinematics. Subjects with previous PT showed higher loading rates than controls,[12, 13] while this was not the case for subjects with PTA.[15] Studies that measured the VGRF of controls and symptomatic subjects came to contradictory results.[10, 16] In general, symptomatic subjects showed larger joint moments in the transverse plane.[10, 11] They also seemed to shift the load away from the knee.[17] The reviewed results regarding the energetics showed that symptomatic subjects generated less knee joint power and work,[12, 16] which is also in line with a pain-minimising strategy. Also, symptomatic subjects may simply be unable to generate more power with the knee because of degenerative changes in the tendon structure. However, this is unlikely because if this were the case a loss of power would also have been expected for subjects of the PTA group, who also show degenerative changes. It is also known that the fibril morphology is abnormal in tendinopathy but the mechanical properties of the tendon aren't.[24] Anyway, the symptomatic subjects examined in the reviewed studies showed a movement pattern (probably due to the associated pain) that is most likely a result of PT and not a cause of it.

Take-off vs. landing

According to one of the main pathophysiological theories about tendinopathy, micro-injuries in the tendon resulting from repeated overload can eventually lead to matrix and cell changes as well as altered mechanical properties of the tendon.[25] Especially eccentric loads are thought to produce micro-injuries because these can be much higher than concentric loads.[26] In contrast with this idea, a study that measured peak patellar tendon torques during (concentric) take-off and (eccentric) landing of a maximal vertical jump found no differences in peak torque between the two phases in healthy subjects.[27] The present review does indicate that differences between groups were found more frequently for the landing phase than the take-off phase, which suggests that subjects who are unable to cope with these peak eccentric patellar tendon torques during landing may be more prone to developing PT. When landing is concerned, there is a difference between landing from a vertical jump, where only vertical deceleration has to be achieved, and landing from a forward jump, where also horizontal deceleration must be achieved. One study that compared the horizontal landing phase (after forward acceleration) and the vertical landing phase during a stop-jump task found that the control group and the PTA group differed more during the horizontal landing phase.[15] Together with the finding that the peak force in the patellar tendon is higher during the horizontal landing phase than the vertical landing phase,[22] this suggests that the horizontal phase may play an important role in the onset of PT. This may also explain why prevalence of PT is highest in volleyball players,[2, 3] because although similar movements are performed in sports like basketball and soccer, the volleyball net forces players to reduce the horizontal velocity to zero during the horizontal landing phase, leading to high loads exerted on the patellar tendon.

Clinical relevance

The present review suggests that risk factors for developing PT are in general 1) flexion angles (small ankle plantar flexion angle, large knee flexion angle) at touchdown that reduce the available ROM, 2) small post-touchdown ROM in the joints, and 3) high post-touchdown joint angular velocities. The landing of a jump also appears to pose a greater threat for developing PT compared to the take-off, a threat that is especially high during horizontal landing after a forward acceleration. This may be relevant for the prevention of this injury, since it suggests that employing a more flexible jumping and landing pattern may reduce the risk of developing PT. This may be achieved in two ways. First, it has been shown that reduced flexibility of the kinetic chain, such as that of the upper leg muscles and reduced dorsiflexion range,[28-30] are related to tendinopathy. For this reason, optimising kinetic chain function (by addressing strength, flexibility and joint function) – one of the main elements of a patellar tendon rehabilitation program according to Kountouris and Cook (2007)[31] – may also be valuable towards preventing patellar tendinopathy. Second, changing stiff landing patterns towards more flexible ones is another preventive option. Indeed, it has been shown that it is possible to modify jump technique by verbal instruction or videotape feedback.[32,33] Before applying such interventions, obviously 'riskful' take-off and landing patterns will have to be detected first. A first step may be to investigate whether experts like trainers and coaches are able to visually recognise 'riskful' take-off and landing techniques, or whether they can be trained to recognise them. Taken together, prevention strategies should focus on kinetic chain function and on changing stiff take-off, especially landing patterns.

The current notion that PT relates to landing technique (involving eccentric loading) more so than the jump take-off (involving primarily concentric loading) supports the idea of using eccentric training in the rehabilitation of PT.[31] To adapt the tendon to eccentric forces may reduce the detrimental effect of such forces. Eccentric exercises may thus also be investigated for their potential use as a preventive measure in addition to their use in rehabilitation.[20]

Finally, future research focusing on risk factors for PT should preferably use a prospective design where data of jump biomechanics are collected at baseline in asymptomatic subjects, who are then followed longitudinally, which will enable us to gain more insight into the causality question. Furthermore, though the subject of study is labelled as a knee problem, joints are evidently connected. Hence in line with the kinetic chain function approach in PT rehabilitation,[31] studying the coordination between joints (see e.g. Hughes et al. (2008), Yeow et al. (2011))[34,35] may provide valuable information about jumping patterns in relation to developing and, accordingly, preventing PT.

Conclusion

We studied the literature for the relation between take-off and landing biomechanics and PT. Although the identified literature was diverse in methods used, jump actions studied and in populations, a synthesis of the literature suggests that PT is mainly caused by factors related to landing rather than take-off. This may raise the question of whether a more appropriate label for this injury would be ‘lander’s knee’ rather than ‘jumper’s knee’. Employing a flexible landing pattern may also be an expedient way to reduce the risk for PT in athletes who take part in sports that involve jump actions. We propose to investigate kinetic chain functioning, eccentric training and particularly changing landing patterns as possible ways to achieve this.

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Chapter 4

Risk factors for patellar tendinopathy in basketball and volleyball players: A cross-sectional study

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Abstract

Patellar tendinopathy has a multifactorial etiology, and many possible risk factors have been described in the literature. Findings are conflicting though, and most research is conducted on elite athletes. Aim of the current study is to determine risk factors for patellar tendinopathy in a large representative sample of basketball and volleyball players. Separate risk factors for men and women, basketball and volleyball players, and athletes with unilateral and bilateral patellar tendinopathy were identified. All basketball and volleyball players between ages 18 and 35 from the Dutch Basketball Association and the Dutch Volleyball Association were invited to complete an online questionnaire on knee complaints and risk factors for patellar tendinopathy. The logistic regression analyses included 2224 subjects. Risk factors for patellar tendinopathy were age, playing at the national level, being male and playing volleyball (compared to playing basketball). Risk factors for men and women were comparable. Among volleyball players outside hitters and middle blockers/hitters had an increased risk compared to setters. For basketball players no risk factors could be identified. No differences in risk factors were found between athletes with unilateral and bilateral patellar tendinopathy. These findings should be taken into account for prevention and rehabilitation purposes.

Introduction

Patellar tendinopathy (PT) is a chronic overuse injury of the patellar tendon, characterised by activity-related anterior knee pain.[1] Actions that require repetitive heavy loading of the knee extensor mechanism, as seen in jumping sports like basketball and volleyball, are supposed to be the cause, and this is the reason why PT is often referred to as jumper's knee.[2] Reported prevalence of PT in elite volleyball and basketball players is 45% and 32% respectively, and is around 11% in recreational basketball players.[3, 4]

PT has a multifactorial etiology, and many intrinsic and extrinsic risk factors have been described in the literature.[5] Conflicting findings preclude the drawing of evident conclusions. Until now most published studies have focused on specific groups (such as elite players) or have used small sample sizes. This makes the results less generalisable, and also makes it impossible to use certain statistical methods like multiple logistic regression.

Detailed knowledge of the etiology of an injury is required to develop interventions and preventive measures.[6, 7] Studying differences in etiology between subpopulations may increase this knowledge. It has been suggested that there may be differences in risk factors for PT between men and women.[8, 9] Since basketball and volleyball are sports with different physical demands, there may also be differences in risk factors for PT between basketball and volleyball players. Some recent studies have also indicated that unilateral and bilateral PT may have distinct etiologies.[8, 10, 11]

The first aim of this study was to identify general risk factors for PT among volleyball and basketball players in a large representative sample. The second aim was to examine whether there are differences in risk factors between (1) men and women, (2) basketball and volleyball players, and (3) subjects with unilateral and bilateral PT.

Materials and methods

Study population and design

All basketball and volleyball players between 18 and 35 years of age from the Dutch Basketball Association (NBB) and the Dutch Volleyball Association (NEVOBO) were invited by email to complete an online survey. This age group was selected to exclude young players with knee pain related to adolescence, such as Sinding-Larsen-Johansson syndrome and Osgood-Schlatter disease, and older players who are diagnosed more often with osteoarthritis – all pathologies that are sometimes

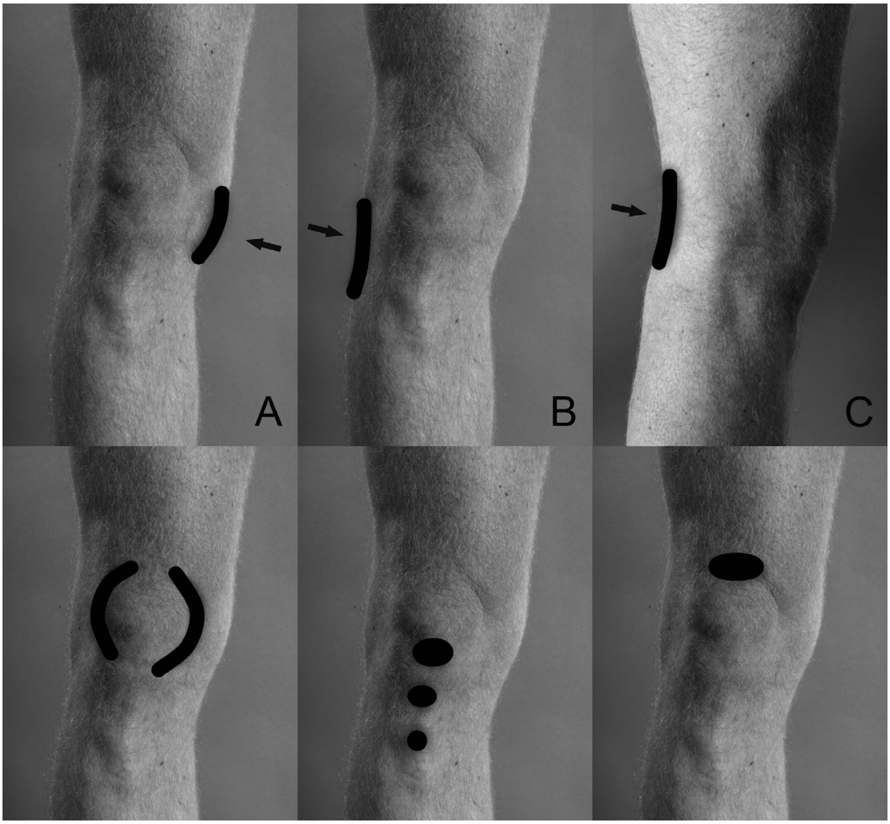

Figure 1. Knee pain map. Subjects selected one picture describing the location of pain most correctly; either A) pain on the medial side of the knee, B) pain on the lateral side of the knee, C) pain on the backside of the knee, D) pain behind and around the patella, E) pain directly under the patella, or F) pain directly above the patella.

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difficult to differentiate from PT. The execution of the survey was performed in co-operation with the NBB and NEVOBO. The survey was conducted at the end of the season between May and June 2008. A total of 2363 respondents, of the estimated 12000 who received an invitation by email, filled out the questionnaire.

Survey

The online survey consisted of questions concerning:

1) *Respondent characteristics:* Subjects answered questions about gender, age and anthropometrics. The anthropometrics obtained were weight, height, waist girth

and hip girth. Using a tape measure, subjects were instructed by pictures to measure hip girth around the hip at the greater trochanter and waist girth around the waist at the navel.

2) Knee injuries: Subjects were asked whether they had a knee injury and for how long, and to indicate the location of pain on a self-administered pain map (figure 1). Subjects were classified as having PT if they indicated on the self-administered pain map that they had pain at the inferior pole of the patella (figure 1E) and/or if they reported that it had been diagnosed by a physician or a physical therapist. Subjects classified as having PT completed the Dutch version of the VISA-P questionnaire.[12, 13] This questionnaire asks for pain, function and sports participation in subjects with PT and is an indication of the severity of PT. The score on the VISA-P questionnaire ranges from 0 to 100 points, with 100 points indicating complete symptom-free sports participation.

3) *Sports participation:* This part of the survey consisted of questions concerning the sport subjects were involved in (basketball or volleyball), years they played either sport, hours of practice in the last week, number of games in the last month, whether they practiced more than last year, how many hours they participated in other sports per week, playing level, playing position and playing surface.

Analysis

After data collection with the online questionnaire there were missing values in the data. There were only missing values for continuous variables. Percentages of missing data for the continuous variables ranged between 0% and 12%, with the exception of waist and hip circumference, for which almost 60% was missing.

Multiple imputation is a technique in which missing values of continuous variables are replaced by $m > 1$ plausible values based on the observed values and estimated relations in the dataset.[14] When a regression analysis is performed on a database with missing data, missing data is deleted casewise (all cases that have missing data on at least one of the variables are excluded). The advantage of using a method to impute missing data is that the full sample size can be analysed, because there are no longer cases with missing data, and no information is lost. Replacing each missing value with multiple estimates gives correct estimates of standard errors, taking into account the increased uncertainty due to missingness and imputation.

The program NORM version 2.03 was used to perform the multiple imputation.[15] NORM is a program that creates multiple imputations for incomplete multivariate data with arbitrary patterns of missing values under an unstructured normal

Table 1. Respondent characteristics.

Total number of respondents	2224	
PT (unilateral/bilateral) / No PT	414(274/140)/1810	(19%/81%)
Men/Women (n)	1006/1218	(45%/55%)
Volleyball/Basketball (n)	1561/663	(70%/30%)
Age (years (mean ± S.D.))	25.4 ± 4.7	
BMI (kg/m^2 (mean ± S.D.))	23.3 ± 3.0	
Waist-to-hip ratio (mean ± S.D.)	0.9 ± 0.1	
Years playing basketball/volleyball (mean ± S.D.)	12.1 ± 5.6	
Hours of training during last week (mean ± S.D.)	4.2 ± 4.3	
Number of games during last month (mean ± S.D.)	2.8 ± 3.5	
Average hours of other sports per week (mean ± S.D.)	1.3 ± 2.2	
Training increase compared to last year (yes/no)	822/1402	
Playing surface (rubber-vinyl/ concrete/ wood-cork-parquet/ respondent does not know)	1366/40/340/478	
Playing Level (national/regional)	219/2005	
Playing position basketball (guard/centre/forward/no fixed position)	135/238/235/55	
Playing position volleyball (setter/ libero-opposite hitter/ outside hitter/ middle blocker-hitter/ no fixed position)	282/197/519/480/83	

model.[16] Variables that were not normally distributed were transformed with the built-in transformation function of NORM to achieve an approximate normal distribution.

Missing data were imputed 10 times, resulting in 10 complete data sets. Simple and multiple logistic regression analyses with the Enter method, with diagnosis of PT (yes/no) as the dependent variable and all the other variables as independent variables, were performed for the total population. Additionally multiple regression analyses were performed for men, women, volleyball players, basketball players, subjects with unilateral PT and subjects with bilateral PT separately. All analyses were performed with SPSS version 16 (SPSS Inc., Chicago) on each of the 10 data sets. The results of these 10 analyses were combined in Excel using the rules given by Rubin (1987) to give parameter estimates and corresponding standard errors.

Because of multicollinearity height, weight, waist circumference and hip circumference were not included in the multiple regression analysis, but BMI and waist-to-hip ratio were. Statistical significance was defined as $p < 0.05$ and a trend towards significance as $p < 0.10$. Because of multiple testing, significance levels and confidence intervals were adjusted using a Bonferroni correction.

Results

The questionnaire was completed by 2363 subjects (estimated response rate = 20%). People that did not meet the inclusion criteria (e.g. age) and people who completed the questionnaire twice were excluded from the analysis, leaving a total of 2224 questionnaires to be analysed. Respondent characteristics are shown in table 1.

The prevalence of PT in the studied population was 18.6%: 12.3 % of the subjects had unilateral PT and 6.3% bilateral PT. Of the 414 subjects who were classified as having PT, 373 were classified based on the self-administered pain map or a combination of a diagnosis (obtained by a physician or a physical therapist) and the self-administered pain map. Median duration of PT in the population was 24 months (range 1–219). Prevalence of PT was higher in men than women (25.3% vs. 13.1% respectively; $\chi^2 = 55.0$, $p < 0.001$). Volleyball players were more likely to have PT than basketball players (20.1% vs. 15.2% respectively; $\chi^2 = 7.1$, $p < 0.01$). The VISA-P score for subjects with PT was 66.2 ± 19.0.

Table 2. Results of the simple and multiple logistic regression analyses for the total population.

	Simple regression analysis		Multiple regression analysis	
	OR	Adjusted 95% CI	OR	Adjusted 95% CI
Age (5-year increase)	0.9	0.7 – 1.1	0.8**	0.6 – 1.0
Gender (men/women), ref = women	2.3**	1.6 – 3.2	2.1**	1.5 – 3.0
Height (5 cm increase)	1.3**	1.2 – 1.4		
Weight (5 kg increase)	1.1**	1.1 – 1.2		
BMI	1.0	1.0 – 1.1	1.0	1.00 – 1.1
Waist girth (5 cm increase)	1.1	1.0 – 1.2		
Hip girth (5 cm increase)	1.0	0.9 – 1.1		
Waist-hip ratio	21.5**	1.7 – 279.8	7.5	0.6 – 101.1
Sport (basketball/volleyball), ref = basketball	1.4	1.0 – 2.0	1.7**	1.2 – 2.4
Years playing basketball/volleyball	1.0	1.0 – 1.1	1.0	1.0 – 1.1
Hours of training last week (5 hours increase)	1.2**	1 – 1.4	1.0	0.9 – 1.2
Training increase compared to last year (yes/no), ref = no	1.4	1.0 – 1.9	1.3	0.9 – 1.8
Number of games last month	1.0	1.0 – 1.1	1.0	1.0 – 1.1
Average hours of other sports per week	1.0	0.9 – 1.1	1.0	1.0 – 1.1
Playing surface, ref = rubber/vinyl				
- *concrete*	2.7*	1.0 – 7.4	2.0	0.8 – 5.2
- *wood/cork/parquet*	1.1	0.7 – 1.7	1.0	0.6 – 1.5
- *respondent does not know*	1.0	0.7 – 1.5	1.0	0.7 – 1.5
Playing level (national/regional), ref = regional	2.2**	1.4 – 3.6	1.9**	1.2 – 3.0

(OR = odds ratio, CI = confidence interval)

** $p < 0.05$ after Bonferroni correction; * $p < 0.10$ after Bonferroni correction

Table 3. Results of the multiple logistic regression analyses for the sub-populations.

	Men (N =1006)		Women (N = 1218)		Basketball (N = 663)		Volleyball (N = 1561)		Unilateral (N = 274)		Bilateral (N = 140)	
	OR	Adjusted 95% CI	OR	Adjusted 95% CI	OR	Adjusted 95% CI	OR	Adjusted 95% CI	OR	Adjusted 95% CI	OR	Adjusted 95% CI
Age (5-year increase)	0.8	0.6-1.1	0.7*	0.5-1.0	0.7	0.5-1.2	0.8*	0.6-1.0	0.8	0.6-1.0	0.7*	0.5-1.0
Gender (men/women), ref = women	NA		NA		1.9	0.9-4.0	2.1**	1.4-3.3	2.2**	1.5-3.3	1.9**	1.1-3.3
BMI	1.0	0.9-1.1	1.0	0.9-1.1	1.1	1.0-1.2	1.0	0.9-1.1	1.0	0.9-1.1	1.0	0.9-1.1
Waist-hip ratio	6.9	0.3-165.2	8.4	0.3-284.2	3.7	0.1-263.8	10.6	0.3-374.9	5.7	0.4-91.6	14.4	0.2-997.1
Sport (basketball/volleyball), ref = basketball	1.7**	1.1-2.7	1.6	0.9-2.9	NA		NA		1.7**	1.1-2.5	1.7*	1.0-3.1
Years playing basketball/volleyball	1.0	1.0-1.1	1.0	1.0-1.1	1.0	1.0-1.1	1.0	1.0-1.1	1.0	1.0-1.1	1.0	1.0-1.1
Hours of training last week (5h increase)	1.0	1.0-1.1	1.0	1.0-1.1	1.0	0.9-1.1	1.0	1.0-1.1	1.0	0.9-1.0	1.0	1.0-1.1
Training increase compared to last year, ref = no	1.3	0.9-2.0	1.3	0.8-2.1	1.0	0.6-1.9	1.5*	1.0-2.1	1.2	0.8-1.8	1.5	0.9-2.5
Number of games last month	1.0	0.9-1.1	1.0	1.0-1.1	1.0	1.0-1.1	1.0	1.0-1.1	1.0	1.0-1.1	1.0	0.9-1.1
Average hours of other sports per week	1.0	0.9-1.1	1.1	1.0-1.2	1.0	0.9 -1.2	1.0	0.9-1.1	1.0	0.9-1.1	1.0	0.9-1.1
Playing surface, ref = rubber/vinyl												
- *concrete*	2.0	0.7-6.4	1.9	0.4-10.6	3.3	0.7-15.3	1.6	0.5-5.3	1.8	0.6-5.7	2.5	0.7-9.0
- *wood/cork/parquet*	1.1	0.6-1.8	0.8	0.4-1.8	0.8	0.4-1.8	1.0	0.6-1.6	0.9	0.6-1.6	1.0	0.5-2.0
- *respondent does not know*	1.1	0.6-1.9	1.0	0.6-1.8	0.8	0.3-1.9	1.1	0.7-1.7	1.0	0.7-1.6	1.1	0.6-2.0
Playing level (national/regional), ref = regional	2.1**	1.1-3.9	1.7	0.8-3.6	1.2	0.5-3.2	2.1**	1.2-3.6	1.9**	1.1-3.3	2.1**	1.0-4.1
Playing position												
Basketball, ref = guard												
- *centre*	NA		NA		1.1	0.5-2.8	NA		NA		NA	
- *forward*	NA		NA		1.3	0.6-3.1	NA		NA		NA	
- *no fixed/standard position*	NA		NA		1.4	0.4-4.9	NA		NA		NA	
Volleyball, ref = setter												
- *libero/opposite hitter*	NA		NA		NA		1.4	0.7-3.0	NA		NA	
- *outside hitter*	NA		NA		NA		2.3**	1.3-4.3	NA		NA	
- *middle blocker/hitter*	NA		NA		NA		2.8**	1.5 – 5.2	NA		NA	
- *no fixed/standard position*	NA		NA		NA		2.3	0.9 – 5.8	NA		NA	

** $p < 0.05$ after Bonferroni correction, * $p < 0.10$ after Bonferroni correction.

Risk factors - Total population

Table 2 shows the results of the simple and multiple logistic regression analyses for the total population. In the simple logistic regression analysis gender, height, weight, waist-to-hip ratio, hours of training per week and playing level showed increased odds ratios (OR's). The multiple regression analysis showed that the odds for PT decrease with age, playing at the national level increased the probability of having PT compared to playing at the regional level, men were at increased odds for PT and the odds for PT in volleyball players was higher than in basketball players.

Risk factors - Sub-populations

Table 3 shows the results of the logistic regression analyses for the sub-populations. Playing volleyball and playing at the national level were risk factors for men, whereas for women only age showed a trend towards statistical significance. For volleyball players being male and playing at the national level were risk factors for PT. Also, playing as outside hitter or middle blocker/hitter was a risk for PT compared to playing as setter. No specific risk factors for basketball players could be identified.

Risk factors for unilateral PT were playing volleyball, being male and playing at the national level. Being male and playing at the national level were also risk factors for bilateral PT. Playing volleyball and age showed a trend towards significance for this last group.

Discussion

Total population

General risk factors for PT that could be identified from the multiple logistic regression analysis were a higher age, playing at the national level, being male and playing volleyball. There were some differences between the results of the simple and multiple regression analyses. Multiple regression analysis takes relations between variables into account and shows which variables are risk factors independent of other (confounding) variables. For example, the finding that length was only significant in the simple analysis may be explained by that the elite basketball and volleyball players are on average taller than non-elite players.

There is no straightforward explanation for the finding that risk decreases with age. It has been suggested that the risk for tendinopathy increases with an age above

30, because of changes in tendon structure and mechanical properties.[17] The present data do not support this, perhaps because only subjects below age 35 are included. The relation between age and risk for PT may be different in this age group. Another explanation may be that subjects who have PT stop playing basketball/volleyball more often, whereas those without injury 'survive'. A third explanation may be that younger athletes very quickly increase the volume and intensity of their loading. Other studies found no association between age and PT.[18, 19] The studies by Witvrouw et al. (2001) and Lian et al. (2003), however, only included students and elite-level players respectively. This led to a smaller age range than the present study, making it less likely to find an association between age and PT.

From previous studies it is known that prevalence in elite basketball players is higher than in recreational basketball players.[3, 4] The present study also shows that the odds for having PT are almost twice as high at the national level compared to the regional level. The reason may be that playing at a higher level is accompanied by a heavier load that is placed on the knee, or that players at the higher level have more muscle power and jump higher.[18] Hours of training per week was only a significant risk factor in the simple regression analysis. Although playing level was a risk factor in the multiple regression analysis, other variables related to knee loading, such as hours of training in the last week, number of games in the last month, training increase compared to last year, hours participating in other sports per week and years playing basketball/volleyball were not additional risk factors for PT. This can be due to the use of the multiple logistic regression analysis. Among the aforementioned variables related to knee loading, playing level is the variable that gives the best prediction for presence of PT. Other variables related to knee loading, such as training hours per week that was statistically significant in the simple regression analysis, may be associated with PT, but they have no additional predictive value above playing level. However, the fact that playing level was a risk factor suggests that other variables related to knee loading, and especially hours of training should be taken into account.

Being male is also a risk factor for PT. The odds are more than twice as high as in women, in line with previous studies that found a higher prevalence for men.[3] This gender difference may be caused by the difference in force-generating capacity of the quadriceps between men and women.[3] It has also been suggested that estrogen affects tendon structure positively.[20]

Compared to playing basketball, playing volleyball is a risk factor for PT. The reason for this difference is unclear. It may be that there are differences in the number of jumps that basketball and volleyball players perform, or in the way they jump. It has been described that elite volleyball players jump higher in a drop jump task than elite basketball players.[21] Another study shows that basketball and volleyball players employ different jumping techniques, adapted to the demands of their sport.[22]

Playing surface was not a significant risk factor in the multiple regression analysis, although there was a trend towards significance in the simple regression analysis. Furthermore, the OR's for concrete in all multiple regression analyses showed an increase compared to rubber/vinyl. Prevalence was around 38% in players who play on concrete, compared to around 20% in players who play on other surfaces. Ferretti et al. (1984) found an increased incidence in players who play on concrete.[23] The finding that the prevalence of PT is much lower in beach volleyball players also suggests that a softer playing surface reduces the risk of PT.[24] A reason that playing on concrete was not identified as a significant risk factor in the present study may be that less than 2% of the respondents played on concrete.

Neither BMI nor waist-to-hip ratio were associated with PT in the total population or sub-populations. Waist-to-hip ratio was significant in the simple regression analysis, but when gender was added to the model this was no longer the case. Crossley et al. (2007) and Malliaras et al. (2007) both found a higher BMI in PT subjects than in controls.[9, 10] A larger waist-to-hip ratio was found in male volleyball players with PT and in subjects with unilateral PT, both compared to controls.[9, 11] Again, the difference between these studies and the present study may be due to the use of multiple logistic regression analysis. In this study BMI and waist-to-hip ratio were not independently associated with PT when accounting for other pertinent variables.

Sub-populations

Playing volleyball and playing at the national level were risk factors for men, whereas for women only age showed a trend towards statistical significance. The OR's however were in the same range for men and women. Cook et al. (2004) showed that jump height was a risk factor for women but not for men,[8] whereas Malliaras et al. (2007) could not identify any risk factors in women but found BMI, waist and hip girth, and waist-to-hip ratio to be associated with PT in men.[9] In the present study no differences were found between men and women on any of the collected variables

Being male and playing at the national level are risk factors for PT in volleyball players. Also players that play as outside hitter or middle blocker/hitter are at a greater risk for PT than those who play as setter, which concurs with findings of Lian et al. (2003) and is probably related to the different demands of these playing positions.[18] A time-motion analysis of volleyball games showed that middles and outsides (including opposites) jumped more during a game than setters.[25] Libero players were not included in that study, but because of their specific defensive role it is very likely that they jump less than players in other positions. Training increase compared to last year and age showed a trend towards being a risk factor for volleyball players.

The separate analysis for basketball players showed no specific risk factors for this group. The smaller number of basketball players makes it more difficult to identify significant risk factors for this subgroup. No specific playing positions were associated with PT, which is in accordance with a time-motion analysis study of basketball players that found no differences in amount of jumping between guards, forwards and centres.[26] Hence in basketball, in contrast to volleyball, no differences in risk for PT between playing positions could be identified.

Some authors have suggested that unilateral and bilateral PT may have distinct etiologies.[8, 10, 11] In the studied population unilateral PT was almost twice as common as bilateral PT, yet risk factors for both conditions were comparable. In the literature though, differences between unilateral and bilateral tendinopathy have been reported for tibia length to stature, eccentric strength, and android distribution of fat and lean mass, waist-to-hip ratio,[11] flexibility in women,[8] and thigh strength and flexibility.[10] Except for waist-to-hip ratio these variables were not collected in the present study, leaving open the possibility for differences in etiology between unilateral and bilateral PT.

Although it is the first to examine etiology in a large representative sample of volleyball and basketball players, this study has several limitations. Some are related to the design of the study, as employing a self-reported questionnaire precludes measurement of more complex variables like flexibility, strength and biomechanical factors. Furthermore, self measurement of anthropometric variables can lead to bias. To minimise this, clear visual and textual instructions were given in the online survey. For waist and hip girth the response was low however. This may be the result of a responder bias; for example obese patients may have skipped these questions. Another reason may be that it takes more effort to measure these variables whereas length and weight are often known by heart. The multiple imputation method takes the increased uncertainty due to missing values of these variables into account. A final limitation related to the design of the study is that a cross-sectional design makes it difficult to draw conclusions about causal relations. A second type of limitation in this study is the low response rate of 20%. There may be two reasons for this. First, web-based surveys generally have lower response rates than other survey methods.[27] This method however made it possible to contact a large population. Second, subjects who have no knee complaints may have been less inclined to complete the survey. This may have caused a selection bias, in turn leading to an overestimation of the prevalence of PT – although it is unlikely that it influenced the outcomes of the risk factor analyses.

A third limitation of this study may have been the use of an online assessment method with a self-administered pain map to classify subjects with PT. It can not be ruled out that this method may have led to the inclusion of patients with other knee pathologies such as for example patellofemoral pain syndrome or fat pad irritation. This method is a feasible way to classify subjects in such a large study population though. From the subjects who were classified as having PT with this method, 45 were invited to participate in a randomised controlled trial. Before inclusion in that trial a clinical examination was performed by an experienced sports medicine physician to make sure the diagnosis of PT was correct. The diagnosis appeared to be correct in 44 of the 45 subjects, demonstrating that the amount of false positives was very low. There is no information available about the number of false negatives.

Perspectives

PT is a frequent and long-lasting injury among basketball and volleyball players. Understanding the etiology of PT is required to develop interventions and preventive measures.[6, 7] The present study used a large representative sample of basketball and volleyball players, making the results generalisable. Age, playing at the national level, being male and playing volleyball (compared to playing basketball) were all associated with PT. The fact that playing level was a significant risk factor, and with that the hours of training per week, indicates that severe knee loading, as seen in elite players, can lead to PT. Individual monitoring of athletes may help prevent PT and reduce complaints. Volleyball players that play as outside hitter or middle block/hitter have the highest odds for PT, therefore changing playing position to libero/opposite hitter or setter may be an option for volleyball players with PT. No risk factors could be identified for basketball players. The present findings should be taken into account for prevention and rehabilitation of PT.

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Chapter 5

The impact of physically demanding work of basketball and volleyball players on the risk for patellar tendinopathy and on work limitations

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Abstract

Patellar tendinopathy is a common injury in jumping athletes. Little is known about work-related etiological factors for patellar tendinopathy and related work limitations. The aim of this study was to identify work-related etiological factors for patellar tendinopathy and to determine the relation between patellar tendinopathy and work limitations. Basketball and volleyball players between 18 and 35 years were invited to complete an online-questionnaire concerning knee complaints, etiological risk factors for patellar tendinopathy and related work limitations. A total of 1505 subjects were included in the analysis. Risk factors for patellar tendinopathy were gender and heavy physically demanding work. The odds for having patellar tendinopathy were significantly higher for heavy physically demanding occupations compared to mentally demanding occupations. 30% of subjects with patellar tendinopathy with a physically demanding job reported to be impaired in their work and 17% reported to be less productive. Basketball and volleyball players with heavy physically demanding work seem to have an increased risk for developing patellar tendinopathy. This finding has important clinical relevance in the treatment of this injury. Working activities should be adjusted in order to reduce the total load on the patellar tendon and help prevention and recovery.

Introduction

Patellar tendinopathy (PT) refers to a clinical condition characterized by activity-related anterior knee pain associated with focal patellar tendon tenderness.[1] Its prevalence is high, especially in jumping athletes, where values of 31.9% in elite basketball players and 44.6% in elite volleyball players have been reported.[2] A prevalence of 11.1% has been reported for recreational basketball players.[3]

The etiology and histopathology of PT have not been completely elucidated so far. PT is considered to be an 'overuse injury' with a failed healing response to repetitive microtrauma.[4, 5] Several risk factors have been described but in a recent review Tiemessen et al. found no studies that looked at occupational risk factors.[6] Knowledge about these risk factors could improve prevention and treatment of PT.

Because successful treatment of PT remains challenging, PT often negatively influences an athlete's career. However, to our knowledge no studies have been published that evaluate the impact of PT on work limitations.

The aim of this study was twofold. First, to identify work-related etiological factors for patellar tendinopathy. Second, to determine the relationship between patellar tendinopathy and work limitations.

Methods

Study population and design

All basketball and volleyball players between 18 and 35 years (n = ± 12000) from the Dutch Basketball Association (NBB) and the Dutch Volleyball Association (NEVOBO) were invited by email to complete an online survey. This was done in cooperation with the NBB and the NEVOBO. The survey was conducted between May and July 2008. A total of 2363 respondents filled out the questionnaire.

Survey

The survey consisted of questions concerning 1) subject characteristics, 2) knee injuries and PT, 3) sports participation, and 4) occupation. In this article the work-related questions will be considered.

1) *Subject characteristics:* Subjects answered questions about gender and age

2) Knee injuries: Subjects were asked whether they had a knee injury, to indicate the location of pain (indicated on a self-administered pain map (figure 1)) and duration of symptoms. Subjects were classified as having PT if they reported that PT had been diagnosed by a physician or a physical therapist. In addition subjects with pain at the inferior pole of the patella - indicated on the self-administered

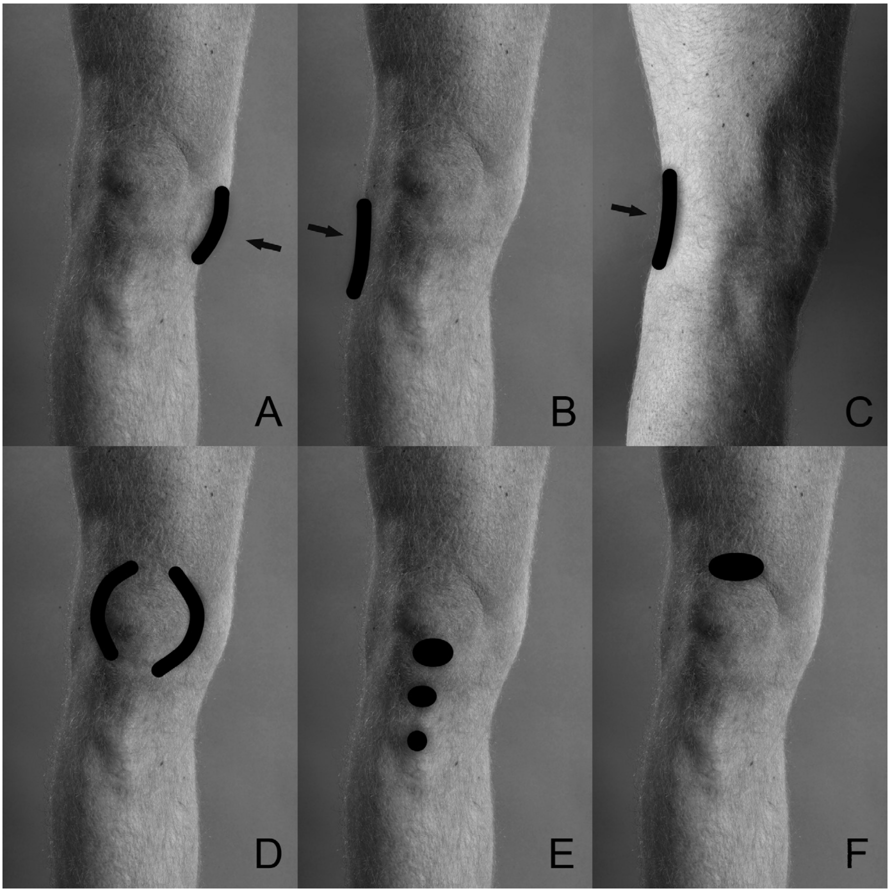

Figure 1. Knee pain map. Subjects selected one picture describing the location of pain most correctly; either A) pain on the medial side of the knee, B) pain on the lateral side of the knee, C) pain on the backside of the knee, D) pain behind and around the patella, E) pain directly under the patella, or F) pain directly above the patella.

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pain map (figure 1E)- were classified as having PT. Several studies have used self-administered pain maps for the inclusion of subjects with PT.[7-9] The location of knee pain as indicated on a self-administered pain map corresponds very well with the actual pain location.[10] Subjects who were classified by this method as having PT also completed the Dutch version of the VISA-P questionnaire.[11, 12] This questionnaire asks for pain, function and sports participation in subjects with PT and is an indication of the severity of PT. The score on the VISA-P questionnaire ranges from 0 to 100 points, with 100 points indicating no symptoms.

3) *Sports participation:* This part consisted of questions concerning the sport sub-

jects were involved in (basketball or volleyball) and hours of practice.
4) *Occupation:* Subjects were asked for their current job title and how much they performed knee loading movements during their job. The knee loading movements were squatting, kneeling, lifting and jumping. Subjects also answered questions about whether they were impaired in their work, less productive in their work and had job absence due to their knee complaints.

Analysis

Reported occupations were classified by two experts (MF and PK) into four categories according to work demands.[13] The four occupational categories were: Mentally demanding work, Mixed mentally/physically demanding work, Light physically demanding work and Heavy physically demanding work. This final category was divided into two new categories. One category contained all sports-related occupations (professional basketball and volleyball players, sports instructors, professional trainers and physical education teachers) and the other category contained the other non-sports-related occupations. This was done since PT is generally considered a sports injury. Putting sports occupations in the same category with other occupations might obscure the results. Only subjects who had a job were included in the analyses.
Results were analyzed using SPSS version 16. Descriptive statistics of subject characteristics, the VISA-P questionnaire and the knee loading movements, prevalence of PT and impact of PT on work were calculated for each occupational category. Logistic regression analyses with the Enter method were performed with diagnosis of PT (yes/no) as the dependent variable. For calculating the odds ratios (ORs) of the different occupations the category with mentally demanding work was chosen as the reference since occupations in this category are the least physical demanding. Gender, using females as reference, and age were included in the regression analyses as covariates. The same logistic regression analysis was also performed with the number of hours the subjects practiced basketball or volleyball per week as an additional covariate. Jobs within occupational categories that showed to be a risk factor for PT were also analyzed separately.

Results

The response rate for the questionnaire was 20%. Of the 2363 respondents 1505 respondents (421 basketball-players, 1084 volleyball-players) were included in the analysis. People without a job (n=775 (including 749 students)) and incomplete

questionnaires (n=83) were excluded from the analysis. Respondent characteristics for the five occupational categories are shown in Table 1.
The prevalence of PT in the total group was 17.8% (basketball 15.0%, volleyball 18.9%). The prevalence was more than twice as high in men compared to women (24.8% vs. 11.9%). The median duration of the PT was 24 (range 1-219) months.

Work related risk factors

Logistic regression analysis showed that gender and the two occupational categories with heavy physically demanding jobs were significantly associated with having PT (Table 2). Since there was a difference in training hours between the occupational categories (Table 1), the same analysis was repeated with the hours the subjects practiced basketball or volleyball per week as an additional covariate. This did not change the results. The other significant contributor to the model was gender. Men have a greater risk for PT than women (OR 2.3, 95% CI 1.8 to 3.1).
The jobs within the two categories with heavy physically demanding work, for which there were 10 subjects or more, were also analyzed separately. For both food & beverage workers (bartenders, waiters, etc) and for professional basket-

Table 1. Characteristics of the study population (data are presented separately for the five occupational categories).

Occupational categories	n	Age: Years (mean ± SD)	Gender: Male (n, %)		Hours of training per week (mean ± SD)	PT prevalence (n, %)	
Mentally demanding work	988	30.0 ± 3.8	468	47.4%	3.4 ± 3.1	167	16.9%
Mixed mentally/ physically demanding work	251	27.2 ± 4.0	85	33.9%	3.7 ± 3.6	35	13.9%
Light physically demanding work	37	26.1 ± 4.7	11	29.7%	3.9 ± 4.0	2	5.4%
Heavy physically demanding work - non-sports-related	184	24.5 ± 4.4	97	52.7%	4.3 ± 4.5	48	26.1%
Heavy physically demanding work - sports-related	45	25.4 ± 4.1	29	64.4%	8.1 ± 7.7	16	35.6%
Total	1505	27.3 ± 4.1	690	45.8%	3.7 ± 3.7	268	17.8%

ball/volleyball players a significant increased risk for PT was found (Table 3).
Figure 2 shows the self-reported knee loading for the five occupational categories. Subjects with light and heavy physically demanding jobs performed more knee loading movements compared to the two other categories. In a logistic regression analysis none of these four knee loading movements showed to be an increased risk for PT. However, the professional basketball and volleyball players differed significantly ($p<0.001$) from all other jobs in number of jumps per day. No differences in self-reported knee loading could be found that accounted for the increased risk in food & beverage workers.

Impact on work

The influence of PT on work limitations is shown in Table 4. The VISA-scores for the five occupational categories were comparable ($F_{4,263}=0.332$, $p=0.85$). More than 25% of the subjects with PT in the occupational categories with physically demanding and mixed mentally/physically demanding jobs were impaired in their work and more than 10% were less productive. People with sports-related jobs were most often impaired and less productive in their work and had the highest job absence due to PT. The median duration of job absence for the 14 subjects who reported job absence was 10 (range 1-120) days with 65% of the job absence lasting less than 15 days. No comparison of job absence duration between occupational groups could be performed because of the low number of subjects that reported job absence.

Table 2. Results of the logistic regression analysis

Covariates	OR	(95% CI)
Gender (male)	2.3	(1.8- 3.1)
Age	1.0	(0.9 - 1.0)
Occupational Category (ref: mentally demanding work)		
Mixed mentally/physically demanding work,	0.9	(0.6 - 1.3)
Light physically demanding work	0.3	(0.1 – 1.3)
Heavy physically demanding work - non-sports-related	1.5	(1.0 - 2.3)
Heavy physically demanding work - sports-related	2.3	(1.2 - 4.4)

** p≤0.01 * p≤0.05

Table 3. Odds ratios (OR's) for the different jobs within the two heavy physically demanding work categories (OR's for jobs with n<10 are not shown).

Occupational category	Job title	N	OR	(95 % CI)
Heavy physically demanding work - non-sports-related	Automotive repair workers	11	1.6	(0.5-5.8)
	Care givers/Nurses	76	1.5	(0.8-2.8)
	Construction workers	20	0.8	(0.3-2.5)
	Food & Beverage workers	22	3.3**	(1.3-8.0)
Heavy physically demanding work - sports-related	Physical education teachers	32	1.7	(0.8-3.8)
	Professional basketball/volleyball players	10	7.8**	(1.9-31.1)

** p≤0.01

Discussion

The main finding of the present study is that heavy physically demanding work seems to be a risk factor for developing PT in people who play basketball or volleyball. Also, PT has a considerable impact on work limitations.

Work related risk factors

As far as we know, this was the first study to investigate the relationship between work related etiological factors and PT. No studies have been published which evaluate occupational risks for developing this specific injury.[6] We found that heavy physically demanding jobs might increase the risk for developing PT in people who also play basketball or volleyball compared to people with mentally demanding work. Risk increased both for people with non-sports-related heavy physically demanding work as well as for people with sports-related heavy physically demanding work. Including the training hours in the analysis had no effect on the risk for people with non-sports-related heavy demanding work, which indicates that the increased risk is independent of training hours.

The increased risk for professional basketball/volleyball players has been described in the literature and it is also the reason why PT is often referred to as jumper's knee.[2, 14] This is also reflected in that professional basketball/volleyball players differed significantly from all other jobs in the number of jumps performed per day. The reason why food & beverage workers show an increased risk for PT is unclear. There is not much literature available on knee injuries in food & beverage workers. One study among hotel restaurant workers reported that 33% had pain in the

Table 4. Impact of PT on work limitations.

	VISA-P score (95% CI)	% of subjects with PT that is impaired in performing their job	% of subjects with PT that is less productive	Job absence in subjects with PT
Mentally demanding work	67.0 (64.4 - 69.7)	8% (14/167)	4% (6/167)	5% (8/167)
Mixed mentally/physically demanding work	67.2 (61.4 – 73.0)	26% (9/35)	11% (4/35)	3 % (1/35)
Light physically demanding work	75.50#	0% (0/2)	0% (0/2)	0% (0/2)
Heavy physically demanding work – non-sports-related	62.4 (56.9 - 68.0)	27% (13/48)	10% (5/48)	4 % (2/48)
Heavy physically demanding work - sports-related	65.7 (56.5 - 74.9)	50 % (8/16)	31% (5/16)	19% (3/16)
Total	66.2 (64.0 - 68.3)	16% (44/268)	8% (20/268)	5% (14/268)

No 95% CI is given since only two subjects in this category were diagnosed with PT

knee/thigh region in the previous month, but no information was given on the type of the injury.[15]

The finding that physically demanding work increases the risk for developing PT might indicate that subjects with these jobs perform certain movements that increase the risk for this injury. It is clear that people with physically demanding work perform more knee loading movements than subjects with mentally demanding work (figure 2). Yet, except for jumping in professional athletes, none of the specific loading movements (squatting, kneeling, lifting and jumping) could be identified as a risk factor for PT. Further research is needed to gain more specific knowledge of which movements can be considered risk factors.

The present findings have important clinical relevance in the treatment of PT. Kountouris & Cook (2007) described a tendon rehabilitation program consisting of three components.[16] One of these components is managing tendon pain by modifying tendon load. Reducing load will diminish symptoms and makes it possible to perform an exercise program. The present findings indicate that working activities should also be taken into account when adjusting the load to the patellar tendon.

Gender

Being male was identified as a risk factor for PT in the logistic regression analysis. The prevalence of PT was about twice as high in men compared to women, which corresponds with a previous study that found the same ratio.[2] According to the authors of that study this gender difference may be explained by the lower force-generating capacity of the quadriceps in women. Another explanation of this difference may be that estrogen plays a protective role.[17] Other studies, however, have shown that estrogen inhibits exercise induced collagen synthesis in the human tendon and leads to a lower rate of tendon tissue repair.[18, 19] Since PT has a multifactorial etiology it is difficult to draw firm conclusions with regard to differences in gender and the role of estrogens.

Impact on work

The results show that PT has a considerable impact on work limitations and productivity. A high percentage of subjects, diagnosed with PT, was impaired in their work or less productive. Since the median duration of PT in the studied population was 24 months, this injury has considerable consequences for employers and employees. The percentage of subjects for whom PT interfered with performing the

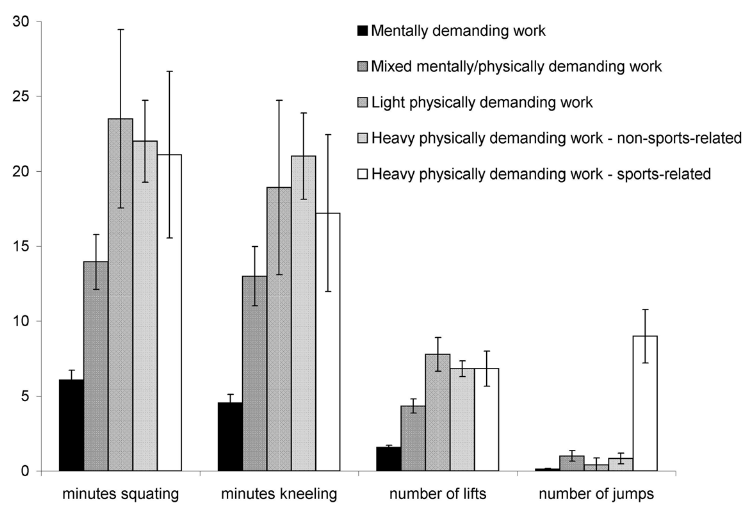

Figure 2. Mean and 95% CI for self-reported knee loading during work per day for the five occupational groups.

job is highest in the sports-related category. This is also the only category where job absence is substantial. This is because PT is a sports injury and it therefore has the most influence on sports-related work. Another reason might be that sports participation requires a near maximal performance.

Although there was a difference between the occupational groups in the impact that PT has on work limitations, the severity of PT as indicated by VISA-P scores was comparable.

Limitations

One limitation of this study is the low response rate of 20%. Online questionnaires have in general a lower response rate compared to other survey methods (e.g. paper or telephone surveys).[20] Because an advantage of an online questionnaire is that more subjects can be approached, the absolute response rate may be comparable to that of other survey methods. Another reason for the low response may be that subjects without knee complaints were less inclined to complete the survey. This may have resulted in a selection bias and an increased prevalence of PT in this study. The influence of this selection bias on the outcomes of risk factors and work limitations is less clear.

The use of an online diagnostic method may also be a limitation. It however appeared to be quite reliable. From the subjects who were classified having PT, 45 were invited to participate in another study. Before inclusion for that study a clinical examination was performed by an experienced sports medicine physician, and PT was diagnosed in 44 of the 45 subjects.

Another limitation of this study is that the studied population may not be representative for all patients with PT since only volleyball and basketball players were invited to complete the questionnaire. It can therefore not be concluded that heavy physically demanding work is a risk factor for PT in people who do not play basketball or volleyball.

The distribution of subjects over the five occupational categories may also be a limitation. A high percentage (66%) of the respondents had mentally demanding work whereas only a small percentage (15%) had heavy physically demanding work. The distribution over the occupational categories in this study, however, seems to correspond with the distribution of the working population in the Netherlands, where almost 50% of the working people have a job that involves computer work and only 20% of the workers regularly perform heavy physically demanding work.[21]

Conclusions

In conclusion, this study shows that sports-related and non-sports-related heavy physically demanding work in basketball and volleyball players are both risk factors for developing PT. This finding has important clinical relevance for treating this injury, and should be taken into account for training and rehabilitation programs. Furthermore, having PT is related with work limitations.

Acknowledgements

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Chapter 6

ESWT for tendinopathy: technology and clinical implications

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Knee Surgery, Sports Traumatology, Arthroscopy (in press)

Abstract

Purpose: The general consensus that tendinopathy, at least in the chronic stage, is mainly a degenerative condition and inflammation plays a minor role has led to a shift from treatments that target inflammation toward treatment options that promote regeneration. One of these treatments is Extracorporeal Shockwave Therapy (ESWT), a physical therapy modality that uses pressure waves to treat tendinopathy. This review was undertaken to give an overview of the literature concerning this treatment, and special attention is given to the differences between focused and radial ESWT.

Methods: A narrative description of wave characteristics, generation methods, and in vitro effects of ESWT is given. The literature on ESWT as a treatment for one common tendinopathy, patellar tendinopathy, was systematically reviewed.

Results: Waves that are generated for focused and radial ESWT have very different physical characteristics. It is unclear how these characteristics are related to clinical effectiveness. Studies into the biological effects of ESWT have mainly used FSWT, showing a number of effects of shockwaves on biological tissue. The systematic review of studies into the clinical effects of ESWT for patellar tendinopathy showed conflicting evidence for its effectiveness.

Conclusion: Physical characteristics of focused and radial waves differ substantial, but effect on clinical effectiveness is unclear. Whereas in vitro studies often show effects of ESWT on tendon tissue, results of clinical studies are inconsistent. Based on the review of the literature suggestions are given for the use of ESWT in clinical practice regarding timing and treatment parameters.

Introduction

Tendon injuries (tendinopathies) are common in the entire population, especially in relation to sports and occupation.[1, 2] Tendinopathy has a complex pathophysiology. It consists of a short acute inflammatory stage but after some time it gradually becomes a degenerative condition.[3]

Because both conservative and surgical management of tendinopathy is not always successful, new treatment modalities have been developed. One of these modalities is Extracorporeal Shockwave Therapy (ESWT). In 2002 Chung & Wiley published a review about ESWT for treating tendinopathies.[4] At that time they concluded based on the literature that there was strong evidence for the effectiveness of ESWT for chronic tendinopathy and that further research was required to settle debates concerning applied energy, number of pulses and number of treatment sessions.

Over the last decade, next to increased knowledge about the pathogenesis of tendinopathy there have been technical developments and an accumulation of studies examining the working mechanisms of ESWT and its effectiveness. One of the main technical developments is that nowadays two different kinds of ESWT are used for treating tendinopathy: focused ESWT (FSWT) and radial ESWT (RSWT). RSWT is relatively new and has made ESWT more affordable and more widely available. These new technologies are the rationale for this review. Most research has been done using FSWT, but research on RSWT is starting to be published. The aim of the present review is to give an up to date description of ESWT, with a special focus on differences between FSWT and RSWT, and review the literature about this treatment method. The overview consists of a description of wave characteristics, methods to generate shockwaves, and in vitro and clinical effects of ESWT, the latter by performing a systematic review with methodological quality assessment on the effects of ESWT for patellar tendinopathy, as an example of a common tendinopathy.

Pressure Waves

Pressure waves (or sound waves) are oscillating mechanical waves that can travel through gas, liquids and solids. A shockwave is a special, non-linear type of pressure wave (Figure 1), characterized by a short rise time. The total duration of a shockwave is around 10 μs.[5, 6]

Both the positive and the negative phase of a shockwave have an effect on interfaces between tissues with different density (acoustic impedance). During the positive phase, shockwaves with high pressure may hit an interface, leading to reflections, or they may pass and gradually become absorbed. The negative (tensile) phase of the shockwave causes cavitation at the tissue interfaces. During cavitation air bubbles are formed as a result of the negative pressure. These bubbles subsequently implode with high speed, generating a second wave of shockwaves or micro-jets of fluid.[5, 6]

Types of ESWT

There are two types of shockwave therapy: focused shockwave therapy (FSWT) and radial shockwave therapy (RSWT). This section will describe wave characteristics of both methods.

FSWT

FSWT is called focused because a pressure field is generated that converges in the adjustable focus at selected depth in the body tissues, where the maximal pressure is reached (Figure 2A). There are three methods to generate focused shockwaves for FSWT: electrohydraulic (EH), electromagnetic (EM) and piezoelectric (PE).[5] All three have in common that the waves are generated in water (inside the applica-

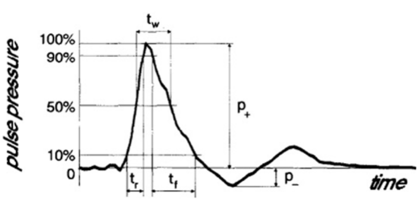
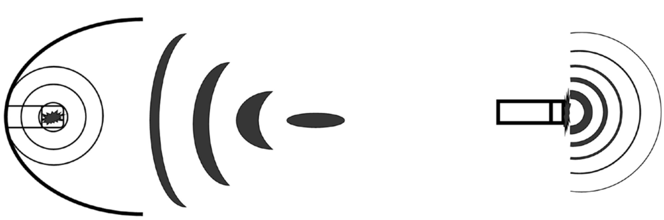


Figure 1. Pressure-time profile of a shockwave (Reprinted from Ultrasound in Medicine & Biology, 21/2, A. Buizza, Dell' Aquila, Giribona and Spagno, The performance of different pressure pulse generators for extracorporeal lithotripsy: A comparison based on commercial lithotripters for kidney stones, pp 259-272, 1995, with permission from Elsevier)



A B

Figure 2. A. Pressure field of a focused shockwave device (EH-generated by means of spark-gap). B. Pressure field of a radial shockwave device

tor). Focused shockwaves are generated in water because the acoustic impedance of water and biologic tissue are comparable. As a result of this, reflection is limited and waves are better transferred into the body.
A difference between these three methods is the moment at which the shockwave forms. EH generators produce focused shockwaves at origin, immediately after the spark-gap, while EM and PE generators form shockwaves nanoseconds later by means of focusation of waves that are generated.[7]

RSWT
The term radial refers to the diverging pressure field of radial shockwave therapy devices, which reach a maximal pressure already at the source (Figure 2B), not at a selected depth in the body. Radial shockwaves for RSWT are generated by accelerating a projectile, using compressed air, through a tube on the end of which an applicator is placed. The projectile hits the applicator and the applicator transmits the generated pressure wave into the body. In contrast to focused shockwave, radial pressure waves are not generated in water.

FSWT versus RSWT
There are two important differences in wave characteristics between focused shockwaves and radial shockwaves. First, radial shockwaves have a more superficial effect, compared to focused shockwaves which reach a maximal energy in the focus that is located deeper into the body tissues (Figure 2).[8] It was shown that a RSWT device generates a pressure field extending to 40 mm in water, whereas the pressure field generated during FSWT may reach a distance that is about twice as high.[8] How these measures relate to biological tissue is not known. These measures are also dependent of the device that is used and the energy setting. In general focused shockwaves will travel further and have more impact on deeper located tissues.
Second, research has shown that pressure waves generated by RSWT from a fundamental point of view cannot be called shockwaves because they lack the characteristic physical features of shockwaves (Figure 3) such as a short rise time, a high peak pressure and non-linearity.[9] A reason for this is that the speed of sound in tissue is around 1500 m/s, whereas the projectile during radial pressure wave generation can only reach a speed of around 20 m/s.[8] This speed is not high enough to generate a real shockwave. Chitniss & Cleveland (2006) found that the rise time (tr) of the generated wave was 25-40 ns for two focused devices (EH), whereas it

was 600 ns for a radial shockwave device.[10] Although 25-40 ns is longer than the definition given above of a shockwave, the waves generated with the EH devices showed the features that are typical for a shockwave (Figure 1), whereas the wave generated with the radial device lacked these characteristics. Based on these findings it may be more correct to use the term *radial pressure wave therapy* instead of *radial shockwave therapy*. Radial pressure wave devices also come with "focused" applicators. However, Cleveland et al. showed that these applicators do not generate real shockwaves either.[9]
Because it is not clear which wave characteristics generate therapeutic effects, it is difficult to relate physical differences between focused shockwaves and radial pressure waves to clinical effectiveness.[11, 12]

Biological Effects of ESWT – In Vitro Studies

Until now most fundamental research on ESWT for tendinopathy has been done with focused shockwaves. Fundamental research into the biological effects of ESWT has been concentrated on a number of non-exclusive theories about the working mechanisms of ESWT in tendinopathy. These theories can be roughly divided into: pain relief, tissue regeneration and destruction of calcifications.

Pain relief

Pain relief with ESWT might work by means of hyperstimulation analgesia.[13] Overstimulation of the treated site would lead to a diminished transmission of signals to the brainstem.[14] Animal studies show that ESWT has an influence on pain transmis-

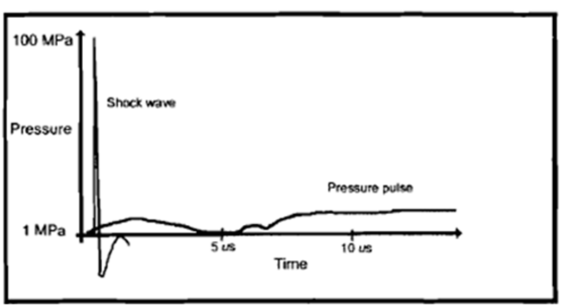


Figure 3. Differences in pressure-time profile of a shockwave (generated with a focused shockwave device) and a pressure wave (generated with a radial shockwave device) (Reprinted from Clinical Techniques in Equine Practice, 2/4, S. McClure and C. Dorfmüller, Extracorporeal Shock Wave Therapy: Theory and Equipment, pp. 348-357, 2003, with permission from Elsevier)

sion by acting on Substance P,[15,16] Calcitonin gene related peptide (CGRP) expression in the dorsal root ganglion,[17] and on neurovascular sprouting,[18] Haake et al. (2002) however found no effect of ESWT on Substance P and CGRP.[19]

Tissue regeneration

A second theory is that ESWT stimulates tissue regeneration. Tissue regeneration by means of ESWT does fit within the framework of mechanotransduction, where mechanical load on the cytoskeleton leads to cell responses and increased protein synthesis.[20] Healthy human tenocytes responded to ESWT with cell growth and increased collagen synthesis,[21] mainly type-I, and in affected human tenocytes, ESWT decreased the expression of matrix metalloproteases (MMPs) and interleukins (ILs) that are associated with tendinopathy.[22] Animal studies show that ESWT leads to an increase in collagen production and matrix turnover,[23-25] increased vascularization in the bone-tendon junction,[26] and increased tissue regeneration in wound healing and ischemia.[27-29]

Destruction of calcifications

Although in vitro studies are lacking, it is thought that ESWT may also destroy calcifications in tendons. This effect is comparable with the way shockwaves are used in lithotripsy to destroy kidney stones. In vivo studies show disintegration of calcifications in shoulder tendinopathy after ESWT.[30, 31]

Clinical Effects of ESWT

Although in vitro studies have demonstrated biological effects of ESWT, clinical effects of ESWT are less clear. In this section we will focus on patellar tendinopathy, as an example of a common sports injury for which ESWT is increasingly used and which has the same underlying pathology as other common (insertional) tendinopathies.[32] A systematic search of the literature was performed to identify randomized controlled trials (RCTs) that studied the effectiveness of ESWT for patellar tendinopathy. The search was performed in the Pubmed and Embase database. Four RCTs were found in this search.[33-36] The methodological quality of the four indentified studies was independently scored by two authors (HW, IA) using the PEDro-checklist.[37] Characteristics as well as the PEDro-score of the four included studies are shown in Table 1.

From this table it appears that, although in vitro studies have demonstrated biological effects of ESWT, the clinical effects of ESWT for treatment of patellar tendi-

Table 1. Overview of systematic reviews on the effectiveness of ESWT for tendinopathy

	Number of patients in analysis (total/ESWT group)	ESWT type	Treatment ESWT group	Treatment control group	Follow-up period	Improvement on VISA-P compared to control	Significant difference?	Pedro score
Peers (2003)	40/21	FSWT (electromagnetic)	3 ESWT treatments -one week interval -1000 impulses -4Hz -0.2 mJ/mm^2 decline squat training	3 placebo ESWT treatments -one week interval -1000 impulses -4Hz -0.03 mJ/mm^2 decline squat training	12 weeks	17.4	Yes	8
Taunton et al. (2003	19/10	FSWT (electromagnetic)	3-5 ESWT treatments -one week interval between treatment 1-3 -2000 impulses -0.17 mJ/mm^2	3-5 placebo ESWT treatments -one week between treatment 1-3 -2000 impulses	12 weeks	3.7	Yes	4
Wang et al. (2007)	50/27 (54/30 tendons)	FSWT (electrohydraulic)	1-2 ESWT treatments -1500 impulses -0.18mJ/mm^2	Conservative treatment (NSAIDS, physiotherapy, exercise program, knee strap and modification of activity levels)	10 – 53 months	47.6	Yes	5
Zwerver et al. (2011)	62/31	FSWT (piezoelectric)	3 ESWT treatments -one week interval -2000 impulses -4Hz -0.25mJ/mm^2	3 placebo ESWT treatments -one week interval -2000 impulses -4Hz -<0.03mJ/mm^2	22 weeks	0.7	No	9

nopathy are less clear. Some studies found ESWT to be effective whereas in others there was no or little improvement. Remarkably, the study that showed the largest improvement was the only one without a placebo intervention.[35]

Discussion

The most important finding of this review was that there is conflicting evidence regarding the effectiveness of ESWT for patellar tendinopathy. This conflicting evidence may have several reasons. First, there is a lack of objective diagnostic criteria for patellar tendinopathy. Second, it may be that ESWT is only effective during certain stages of tendinopathy and not during other stages. A third reason may be that there are many instrumental settings — like choice of generator (EH, EM, or PE), focal depth, number and intensity of pulses (energy flux density) — that can be varied and which may play a role in the effectiveness. A last reason it a methodological one.

These four topics will be described below. These topics are also of importance for research into the effectiveness of other tendinopathies where also conflicting results have been shown.[38-40]

Diagnosis

There is no gold standard for the diagnosis of tendinopathy. This diagnosis is obtained from a combination of history of symptoms and physical examination.[41] Imaging increases the likelihood of a correct diagnosis, but is not conclusive. The ab-

Table 2. Treatment parameters

Treatment parameter	Description
Maximal positive pressure	The maximal positive pressure that is reached
Focal zone	A 3- dimensional ellipsoid where the pressure is above a certain value
Energy flux density	The amount of energy per surface unit (mJ/mm^2)
Time interval between treatments	
Number of impulses per treatment	
Impulse frequency	The number shockwaves that is applied per second
Localization method	How the to-be-treated site is determined
Anesthesia	
Concurrent treatments/Rest	

sence of a gold standard may result in non-uniform populations in clinical studies.

Stage of tendinopathy

Effectiveness of ESWT may depend on the stage of tendinopathy. A recent model of tendinopathy differentiates between a *reactive tendinopathy/early tendon disrepair phase* and a *late tendon disrepair/ degeneration phase*.[42] ESWT seems most appropriate in the latter where the tendinopathy is degenerative and when conservative treatment has no effect.[2, 42] This is also supported by recent studies that showed no effect of ESWT in the early stage of tendinopathy.[36, 43] Until now studies have not differentiated between subjects in the study based on these different stages, therefore different studies may have used populations that are not comparable.

Treatment parameters

There are a number of instrumental settings that can be varied during ESWT (Table 1). The exact relation between these settings and effectiveness of the treatment are often unclear, although for some settings there is some indication as to how they may influence effectiveness.

Energy flux densities above 0.50 mJ/mm^2 should be avoided.[14, 44] Bosch et al. (2009) showed in an animal study that EH-generated shockwaves already have a major impact on healthy tendon tissue at an intensity of 0.14 mJ/mm^2.[24]

Little is known about the optimal number of impulses in tendinopathy, one study showed that three treatments with 500 impulses was more effective than three treatments with 100 impulses in plantar fasciitis.[45]

High frequencies do not seem advisable as cavitation bubbles may block propagation of subsequent waves,[6] and the maximum generated pressure seems to drop.[7]

Localization of the site that needs treatment can be determined by means of palpation, ultrasound or radiographs. The relation between these localization methods and pathology is not always clear though.[46-48]

The use of anesthesia during ESWT seems not advisable as three studies comparing ESWT with and without anesthesia showed that treatment without anesthesia is more effective.[49-51]

Rest seems to be important in the first phase after ESWT treatment. Heavy physical activities are best avoided in this phase because the tendon can bear less load shortly after ESWT.[24] This is in line with a recent study that showed no effect of ESWT in actively competing athletes.[36] Although research is scarce, a combination of treatments may have a synergistic effect and lead to better results. Two studies found better results for a combination of ESWT and eccentric exercises than for eccentric exercises alone.[33, 52] Further research on these topics is required.

Methodology

To prevent that natural improvement, which may be possible in the early stages of tendinopathy, is mistaken for a treatment effect it is important to include a placebo control group in ESWT effectiveness studies. Furthermore, studies should have a long enough follow-up time to discover treatment effects, since it is known that the metabolic turnover rate of tendon tissue is slow. These methodological issues may also explain some of the conflicting result found for the effectiveness of ESWT.

Clinical effectiveness of FSWT versus RSWT

All four RCTs included in the systematic review on patellar tendinopathy used focused shockwave devices. This may be because radial shockwave devices have been introduced recently. Therefore no conclusions can be drawn with regard to the effectiveness of RSWT for patellar tendinopathy. For plantar fasciitis two RCTs have been published that looked at the effect of RSWT.[53, 54] Both studies found RSWT to be effective for this condition. No other placebo controlled studies on the effectiveness of RSWT for treating tendinopathy have been published. There is some evidence from non-placebo controlled studies that RSWT is effective for Achilles tendinopathy.[52, 55]

Until now, only one study has directly compared the effectiveness of FSWT and RSWT,[56] using both methods to treat plantar fasciitis, and a small difference in favor of FSWT was found. The authors do not hypothesize about what may be the cause of this difference though. Maybe FSWT was more effective because the plantar fascia is located deep in the body (compared to other tendons), so it is better reached with the waves generated by means of FSWT, which achieve their maximal energy within the focus. However, because RSWT also is shown to be effective for treating plantar fasciitis,[53, 54] these waves, with a pressure field that reaches around 40mm in water, probably also travel far enough in tissue to reach the affected area. It is therefore based on the present clinical literature not possible to recommend one of the two types of ESWT over the other.

Conclusion

Although evidence for the effectiveness of ESWT for treating tendinopathy is in-

consistent, it is used widely in sports medicine. The present overview aimed at describing ESWT, in particular the two types that are used: FSWT and RSWT. Waves that are generated for FSWT and RSWT have very different physical characteristics. The relation between these characteristics and clinical effectiveness is unclear. Studies into the biological effects of ESWT have mainly used FSWT, showing a number of effects of shockwaves on biological tissue. Clinical effects of ESWT for (patellar) tendinopathy are less clear. Reasons for this may be the non-uniform inclusion criteria related to the absence of a diagnostic gold standard, populations from different pathological stages, the large number of treatment parameters that can be varied and methodological issues.
It remains therefore questionable whether ESWT should be recommended at all. This is probably also the case for most other tendinopathies for which also conflicting findings regarding the effectiveness of ESWT have been reported. Further research is required to determine the value of ESWT for tendinopathy. This research should consist of a combination of in vitro and clinical studies. Studies with clear descriptions of study populations, diagnostic criteria and treatment parameters and concurrent rehabilitation programs / tendon loading activities are necessary to advance research.

Clinical implications

This review provides some suggestions for the use of ESWT in clinical practice. When ESWT is used to treat tendinopathy, it seems best to apply it in a later stage,[42] in combination with tendon load management,[57] after other conservative options have been tried and before more radical options like surgery are considered. Based on the literature, low energy, a low frequency, no anesthetics and exercise after an initial rest period can be recommended. At the moment no recommendation can be given as to which of the two types of ESWT should be used.
The introduction of RSWT next to FSWT made ESWT more affordable and easier to administer. However, there is no agreement in the literature as to whether ESWT is effective for tendinopathy, hence at the moment there is no information available as to which of the two methods is preferable.

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Chapter 7

The TOPSHOCK study: Effectiveness of radial shockwave therapy compared to focused shockwave therapy for treating patellar tendinopathy. Design of a randomised controlled trial

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Abstract

Background: Patellar tendinopathy is a chronic overuse injury of the patellar tendon that is especially prevalent in people who are involved in jumping activities. Extracorporeal Shockwave Therapy is a relatively new treatment modality for tendinopathies. It seems to be a safe and promising part of the rehabilitation program for patellar tendinopathy. Extracorporeal Shockwave Therapy originally used focused shockwaves. Several years ago a new kind of shockwave therapy was introduced: radial shockwave therapy. Studies that investigate the effectiveness of radial shockwave therapy as treatment for patellar tendinopathy are scarce. Therefore the aim of this study is to compare the effectiveness of focussed shockwave therapy and radial shockwave therapy as treatments for patellar tendinopathy.

Methods/design: The TOPSHOCK study (Tendinopathy Of Patella SHOCKwave) is a two-armed randomised controlled trial in which the effectiveness of focussed shockwave therapy and radial shockwave therapy are directly compared. Outcome assessors and patients are blinded as to which treatment is given. Patients undergo three sessions of either focused shockwave therapy or radial shockwave therapy at 1-week intervals, both in combination with eccentric decline squat training. Follow-up measurements are scheduled just before treatments 2 and 3, and 1, 4, 7 and 12 weeks after the final treatment. The main outcome measure is the Dutch VISA-P questionnaire, which asks for pain, function and sports participation in subjects with patellar tendinopathy. Secondary outcome measures are pain determined with a VAS during ADL, sports and decline squats, rating of subjective improvement and overall satisfaction with the treatment. Patients will also record their sports activities, pain during and after these activities, and concurrent medical treatment on a weekly basis in a web-based diary. Results will be analysed according to the intention-to-treat principle.

Discussion: The TOPSHOCK study is the first randomised controlled trial that directly compares the effectiveness of focused shockwave therapy and radial shockwave therapy, both in combination with eccentric decline squat training, for treating patellar tendinopathy.

Trial registration: Trial registration number NTR2774.

Background

Patellar tendinopathy (PT) is a chronic overuse injury of the patellar tendon characterised by activity-related anterior knee pain.[1] Actions that require repetitive heavy loading of the knee extensor mechanism as seen in jumping sports like basketball and volleyball are supposed to be the cause, and this is the reason why PT is often referred to as jumper's knee.[2] PT is an injury that can last for years.[3] Several treatment options have been described in the literature, such as rest, anti-inflammatory drugs, physical therapy (eccentric exercises), injections and surgical treatments.[4]

Another treatment option for patellar tendinopathy is Extracorporeal Shockwave Therapy (ESWT), a method that was originally used for lithotripsy (kidney stone fragmentation). ESWT uses shockwaves to treat the affected area. A review of the literature concluded that ESWT seems to be a safe and promising treatment for PT, although more research is necessary.[5] The study that showed the most convincing evidence for its effectiveness in treating PT used a combination of ESWT and eccentric training.[6] It seems therefore important to combine these two treatment modalities.

Some years ago shockwave generators were introduced which do not generate focused shockwaves. These generators have a ballistic source that generates radial shockwaves. Cleveland et al. (2007) showed that radial shockwave generators do not generate real shockwaves and that they act only superficially on the tissue.[7]

Nowadays radial shockwave generators are often used because they are more affordable than focused shockwave generators. There is however only one study that has investigated the effectiveness of radial shockwave therapy in treating patellar tendinopathy. Lohrer et al. (2002) demonstrated significant effects on pain and function, suggesting that radial shockwave therapy is an effective treatment for patellar tendinopathy.[8] Their study however was non-randomised and had no control group, making it difficult to draw firm conclusions regarding the effectiveness of radial shockwave therapy. Another study by the same group directly compared the effectiveness of radial and focused shockwave therapy for treating plantar fasciitis,[9] and that study found a small difference in favour of focused shockwave therapy.

So far no studies have directly compared the effects of focused shockwave therapy and radial shockwave therapy in patellar tendinopathy in one single randomised controlled study. The aim of the TOPSHOCK study is therefore to compare the effectiveness on patellar tendinopathy of both therapies in combination with eccentric decline squat training in a blinded, randomised study.

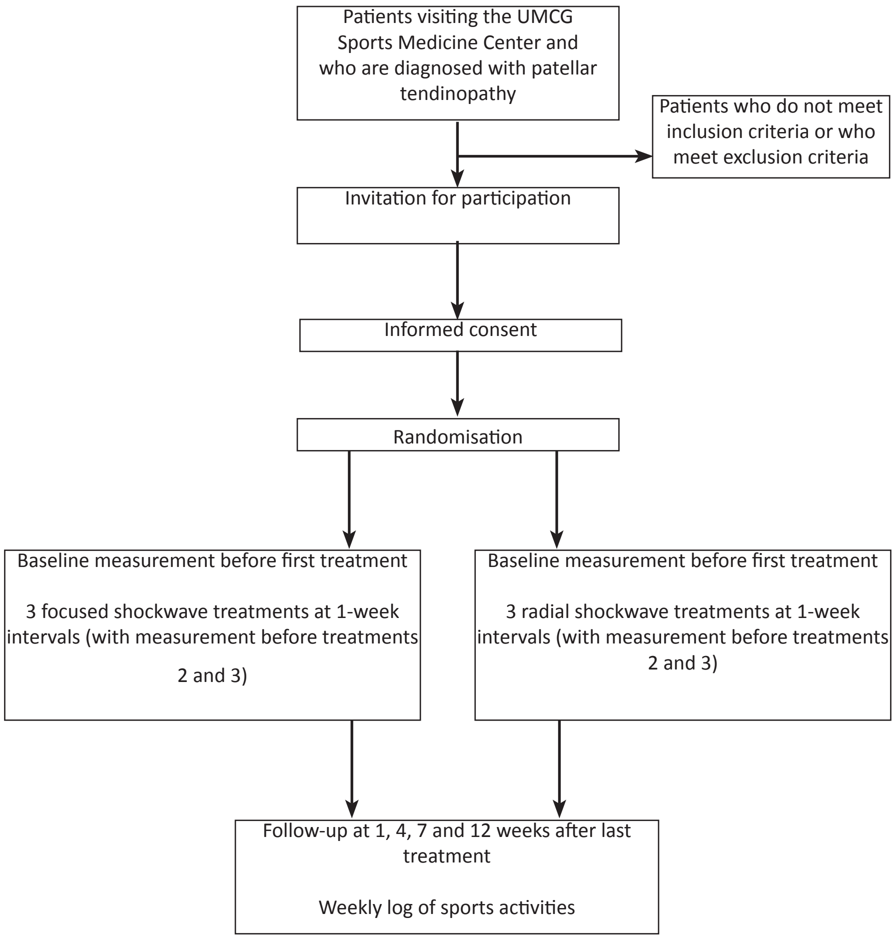

Figure 1. Flowchart of the TOPSHOCK-study

Methods/Design

Design

The TOPSHOCK study (Tendinopathy Of Patella SHOCKwave) is a two-armed randomised controlled trial. The flow chart of the trial is shown in figure 1. Patients undergo three sessions of either focused shockwave therapy or radial shockwave therapy in combination with eccentric decline squat training. Outcome assessors and patients are blinded as to which treatment is given. Treatment takes place

between June 2010 and November 2011. A baseline measurement will be taken before treatment session 1. Measurements will also take place preceding treatment sessions 2 and 3. Sessions are spaced at 1-week intervals. Follow-up measurements are taken at 1, 4, 7 and 12 weeks after treatment session 3. Two weeks after the final treatment session patients start with a home-based training program consisting of eccentric decline squat training.
The study was approved by the Medical Ethics Committee (Number 2009/322) of the University Medical Center Groningen, The Netherlands. Participants have to provide informed written consent before randomisation.

Study population
Patients with PT who visit the Center for Sports Medicine of the University Medical Center Groningen and are diagnosed with PT by an experienced sports medicine physician, and who meet the inclusion and exclusion criteria, are invited to participate in the study.

Inclusion and exclusion criteria
Patients eligible for inclusion in this study must meet the following criteria: 1. A history of pain in the patellar tendon or its patellar or tibial insertion in connection with training and/or competition; 2. Symptoms for over three months (to exclude acute inflammatory tendon problems and de novo partial ruptures); 3. Age between 18 and 50 (to reduce chances of other osteochondrotic diseases like Sinding-Larsen-Johanson, Osgood-Schlatter and osteoarthrosis); 4. Palpation tenderness of the patellar tendon; 5. A score below 80 on the VISA-P questionnaire (see measurements section).[10, 11]
Exclusion criteria for the study are: 1. Acute knee or patellar tendon injuries; 2. Chronic joint diseases; 3. Signs or symptoms of other coexisting knee pathology; 4. Contraindications for ESWT (pregnancy, malignancy, coagulopathy); 5. Knee surgery or injection therapy with corticosteroids in the last three months; 6. Daily use of drugs with a putative effect on patellar tendinopathy in the last year (e.g. non-steroid anti-inflammatory drugs, fluorchinolones), or use of anticoagulants.

Randomisation
Blockwise randomisation is performed by an independent researcher of another department with a computer-generated randomisation list. This researcher informs the physical therapist who administers the shockwave treatment about the

treatment allocation. Patients' allocation will be concealed from the patients and the outcome assessors at all times during the trial.

Intervention

Both focused and radial shockwave therapy will be given by one experienced independent physical therapist. Shockwave therapy is applied with a shockwave device that has two applicators and can therefore generate both focused and radial shockwaves (Duolith SD1, Storz Medical, Tägerwilen, Switzerland). Both shockwave interventions will be administered without local anaesthesia, since several studies have shown that treatment without anaesthesia is superior to treatment with anaesthesia.[12-14]

Focused shockwave therapy

Focused shockwave is applied with the focused applicator of the shockwave device. Three sessions will be administered at one-week intervals. Each session consists of 2000 impulses at 4 Hz. The energy flux density is 0.12 mJ/mm^2, since this corresponds with 2.4 bar on the radial shockwave generator of the used machine (personal communication with manufacturer, 18 May 2010). A fixed energy intensity was chosen instead of a patient guided energy intensity. A patient guided energy intensity may influence the results because one method may be more painful compared to the other method, therefore leading to a difference in energy intensity level between groups. Rompe et al. (2008) used 2.4 bar for effectively treating insertional Achilles tendinopathy,[15] with favourable results and no report of dropouts because of the treatment being to painful. Since PT is often also an insertional tendinopathy the same intensity was chosen in the present study. The patient will be in supine position with the knee slightly flexed. Transmission gel is applied between the applicator and the skin. The applicator is slowly moved around the point of maximal tenderness.

Radial shockwave therapy

The procedure for radial shockwave treatment is the same as for focused shockwave therapy, the only difference being that impulses are applied at 8 Hz and the treatment intensity is 2.4 bar.

Eccentric decline squat training

Both treatment groups will be given a standard home-based program for tendon training. Peers (2003) showed that combining ESWT with eccentric decline squat training gave positive results,[6] therefore this is also applied in the present study. The home program consists of performing squats on a decline board.[16] Three sets of 15 repetitions twice a day for 5 days a week will be prescribed.[17] Performing the exercises takes approximately 10 minutes per day. The physical therapist will give instructions on the home training program during the last treatment session. Patients start with the home program two weeks after the last treatment session and continue until the end of the trial (12 weeks post-treatment). The decline squats should be performed with mild pain (VAS < 4). If pain decreases, load will be increased by adding load in a backpack.

Concurrent sports participation and medical treatment

Patients will be allowed to keep on participating in sports activities. If there is an increase in pain in the first 48 hours after treatment the participant will be advised to take paracetamol up to a maximum dose of 3 dd 1000 mg.

Measurements

Baseline measurements

Patients will complete the Dutch VISA-P (Victorian Institute of Sport Assessment) questionnaire at baseline.[10, 11] The VISA-P questionnaire is designed to measure severity of patellar tendinopathy. The VISA-P score is the primary outcome variable. Patients will also complete a baseline questionnaire that asks for demographics, sports participation and medical history, knee injuries and previous treatment. Anthropometrics of the participants are also collected. Pain experienced during ADL and sports will be rated on a VAS. Finally, pain during one and during 10 decline squats on a 25° decline board is rated on a VAS.

Follow-up measurements

At all follow-up moments (before treatments 2 and 3 and 1, 4, 7 and 12 weeks after treatment) the VISA-P questionnaire is completed. At the 7-week and 12-week follow-up pain VAS score during ADL, sports and functional tests (decline squat) are also collected. At these two moments patients answer a question about subjective improvement and their overall satisfaction with the treatment. A follow-up of 12 weeks was chosen because Peers et al. showed favourable effects of a similar protocol within a 12-week period.[6] Adverse reactions and side effects will also be recorded during the follow-up period.

Web-based diary

Every week the patients will record their sports activities, pain during and after these activities, and concurrent medical treatment in a web-based diary.

Sample size

Sample size is calculated based on the VISA-P score 12 weeks after treatment. A baseline score of 64 points is expected in symptomatic subjects with an SD of 19 points, based on previous investigations.[18] A difference in the VISA-P score of 15 points at the end of the study (12 weeks) is considered to be clinically relevant. With a power of 80% and an alpha of 5%, 28 tendons per group are needed to detect a difference of 15 points between treatments on the VISA-P questionnaire. Since Peers reported no drop-out of patients because of pain (during or after treatment) in a similar protocol,[6] we do not expect a higher-than-normal drop-out rate.

Statistical analyses

Results will be analysed using SPSS version 16 (SPSS, Chicago) according to the intention-to-treat principle. Descriptive statistics will be used to describe the characteristics of the focused and the radial shockwave group and the outcome variables at the evaluation moments. The difference on outcome variables between treatment groups after 12 weeks will be assessed using t-tests. A repeated-measures analysis will be used to determine whether there is a difference on outcome variables between the two groups over time. Analyses will be performed for the primary and secondary variables. A p-value < 0.05 is considered statistically significant.

Discussion

A number of studies have been conducted on the effect of shockwave therapy for patellar tendinopathy. A review of the literature concluded that ESWT seems to be a safe and promising treatment for PT.[5] All included studies except one used focused shockwave therapy.

Radial shockwave generators generate waves that are very different from those generated by focused shockwave generators. Radial shockwaves lack the characteristic features of shockwaves such as a short rise-time, a high peak pressure and non-linearity.[7] Another difference is that radial shockwaves have a more superficial effect on tissue, compared to focused shockwaves which reach a maximal energy in the focus that is located deeper into the tissue.[19] Since the exact working mechanism of shockwave therapy is not well understood, this difference does not imply that radial shockwave therapy is less effective than focused shockwave therapy.[20,21] Each therapy may even have a different working mechanism.[22]

It is not known whether there is a difference in effectiveness between these therapies as treatment for PT. Therefore, the aim is of this study is to directly compare the effects of focused shockwave therapy and radial shockwave therapy on patellar tendinopathy in a blinded randomised controlled trial.

Conclusions

The TOPSHOCK study is the first blinded randomised controlled trial that directly compares focused shockwave therapy and radial shockwave therapy in combination with eccentric decline squat training for the treatment of patellar tendinopathy.

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Chapter 8

No difference in effectiveness between focused and radial shockwave therapy for treating patellar tendinopathy: A randomized controlled trial

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Submitted

Abstract

Background: As for treating patellar tendinopathy with Extracorporeal Shockwave Therapy (ESWT), there is a discrepancy between the results of scientific research, which is mostly based on studies using focused shockwave therapy (FSWT), and clinical practice, where the use of radial shockwave therapy (RSWT) is more common.

Objective: To compare the effectiveness of FSWT and RSWT for treating patellar tendinopathy.

Design: A randomized controlled trial

Setting: Center for Sports Medicine of a University Medical Center.

Patients: Subjects clinically diagnosed with patellar tendinopathy.

Intervention: Patients were randomized into two groups. One group received three sessions of FSWT and the other group received three sessions of RSWT. Both groups received the same eccentric training program.

Measurements: Measurements took place at baseline and 1, 4, 7 and 14 weeks. The primary outcome measure was the VISA-P questionnaire. Secondary outcome measures were pain during ADL, sports activities and the decline squat.

Results: 21 subjects (31 tendons) received FSWT and 22 subjects (26 tendons) received RSWT. Both groups improved significantly on the VISA-P score, but there were no differences in improvement between the FSWT group (15.0 points) and the RSWT group (9.6 points, p=.30). The same trend was seen in the secondary outcome measures.

Limitations: No firm conclusions can be drawn regarding the effectiveness of ESWT because no placebo or control group was studied.

Conclusions: There were no differences in effectiveness between FSWT and RSWT as treatment for patellar tendinopathy. It is therefore not possible to recommend one treatment over the other. Both groups improved significantly over time, although it is questionable whether this improvement is clinically relevant.

Introduction

Patellar tendinopathy (PT) is a chronic knee injury that is often therapy-resistant.[1, 2] Conservative and surgical treatment of PT are not always successful, hence new treatment options are being developed. One of these treatments is Extracorporeal Shockwave Therapy (ESWT). A systematic review of the literature concluded that ESWT is a safe and promising treatment for PT, but that further research was necessary, especially as different shockwave devices were used.[3] The review identified seven studies, six of which used a traditional focused shockwave device. The remaining study used a radial shockwave device, a technology that has been introduced more recently.[4] One might expect a difference in effectiveness since there are differences between the technologies of focused shockwave therapy (FSWT) and radial shockwave therapy (RSWT). As described elsewhere waves for FSWT can, depending on the device, be generated by means of electrohydraulic, electromagnetic and piezoelectric mechanisms.[5] In all three generation methods a wave is generated in water inside the applicator (in this case by means of an electromagnetic mechanism), and this wave is subsequently focused by a lens and transmitted into the tissue. Waves for RSWT are generated by accelerating a projectile, by means of compressed air, through a tube at the end of which it hits an applicator that makes contact with the skin. Because of this there are important differences between the waves that each technology produces. First, radial shockwaves have a more superficial effect, as the maximal energy is reached at the skin, compared to focused shockwaves which reach a maximal energy in the focus that is located deeper into the body tissues.[6] Second, it has been shown that pressure waves generated by RSWT from a fundamental point of view cannot be called shockwaves because they lack the characteristic physical features of shockwaves such as a short rise time, a high peak pressure and non-linearity.[7]

As mentioned above, like most clinical effect studies in-vitro studies looking at the effects of ESWT on tissue also use focused shockwave devices the most often. However, in physical therapy clinics in the Netherlands radial shockwave therapy (RSWT) is used to treat PT by far more practitioners (in a ratio of 4:1) than focused shockwave therapy (FSWT).[8] This may be related to the fact that these devices are more affordable. There is thus a discrepancy between the results of scientific research on treating PT with ESWT, which is mostly based on studies with FSWT, and clinical practice, where the use of RSWT is more common. The aim of this study is therefore to fill this gap by comparing the effects of FSWT and RSWT for the treatment of PT.

Methods

Design overview

The TOPSHOCK study was a randomized controlled trial with blinded outcome assessors and blinded participants and a follow-up of 14 weeks, conducted in the Netherlands (trial number NTR 2774). A complete description of the study protocol has been published before.[9]

Setting and participants

The study took place at the Center for Sports Medicine of University Medical Center Groningen between May 2010 and October 2011. Approval was obtained from the local medical ethics committee (Number 2009/322) prior to the study. Participants provided verbal and written informed consent before the study.

Subjects who visited the Sports Medicine Center of University Medical Center Groningen and were diagnosed there with PT by experienced sports medicine specialists, were asked to participate in the study. Subjects aged between 18 and 50 were eligible if they reported a history of pain in the patellar tendon or its insertions in connection with training and/or competition, these symptoms were present for at least three months, there was palpation tenderness of the patellar tendon, and the VISA-P (Victorian Institute of Sport Assessment – Patella) score was below 80 points. Acute knee or patellar tendon injuries, chronic joint diseases and other coexisting knee pathology, knee surgery or injection therapy in the preceding three months, daily use of drugs with a putative effect on PT (e.g. non-steroid anti-inflammatory drugs) or use of anticoagulants were reasons to exclude subjects.

Sample size was calculated based on the VISA-P score 12 weeks after the last ESWT treatment. A difference in the VISA-P score of 15 points at the end of the study (12 weeks) was considered to be clinically relevant. Based on previous studies a baseline score of 64 points was expected in symptomatic subjects with an SD of 19 points.[13] With a power of 80% and an alpha of 5%, 28 tendons per group were needed to detect a clinical relevant difference.

Randomization and Interventions

An independent researcher from another department did a computerized randomization of participants to one of the treatment groups to receive either FSWT or RSWT, both in combination with personally instructed eccentric decline board training. Treatment allocation was concealed from the subjects and the outcome assessors at all times during the trial. Shockwave treatment was applied with a Storz Duolith SD1 (Storz Medical AG, Tägerwilen, Switzerland) that can deliver both (electromagnetic) FSWT and RSWT. Both groups received three ESWT sessions from the same physical therapist (M.H.) with a one-week interval. During each session 2000 pulses were delivered, at 4 Hz and an intensity of 0.12 mJ/mm2 to the FSWT group and at 8 Hz and an intensity of 2.4 bar to the RSWT group. The intensities that were used during FSWT (0.12 mJ/mm^2) and RSWT (2.4 bar) were comparable (personal communication with manufacturer, May 2010). If both legs of a subjects were treated, they received the same treatment for both legs.

All subjects performed an eccentric exercise program that started two weeks after the final ESWT treatment. This program consisted of performing single-leg squats on a decline board.[10] Three sets of 15 repetitions twice a day for 5 days a week had to be performed. Subjects received instructions on how to execute the exercises. They were advised to experience some pain, around 4 on a visual analog scale (0 = no pain, 10 = worst pain ever), during the execution of the squats. If less pain was experienced they were advised to increase the load by using a backpack with extra load. Subjects were advised to reduce load during the treatment period and the first weeks after treatment.

Outcomes and follow-up

Primary outcome was improvement on the VISA-P questionnaire at the final follow-up.[11, 12] This questionnaire asks for pain, function and sports participation in subjects with PT and is an indication of the severity of PT. The score on the VISA-P questionnaire ranges from 0 to 100 points, with 100 points indicating complete symptom-free sports participation. The questionnaire was completed at baseline and 1, 4, 7 and 14 weeks after the final treatment. Secondary outcome measures were VAS pain score during ADL, during sports activities and during the decline squat and the subjective rating of improvement. These outcome measures were collected 7 and 12 weeks after the final treatment. Pain experienced during the ESWT treatment was also measured using a VAS pain score. All outcome measures were collected by blinded outcome assessors. Subjects also completed a web-based logbook in which they reported the number of training sessions and matches they participated in as well as their compliance with the eccentric exercise program.

Statistical Analysis

Analyses were performed according to the intention-to-treat principle (last observation carried forward), using SPSS version 18 (IBM SPSS inc., Chicago, IL). Generalized Estimating Equations (GEE) analyses were performed on the continuous outcome variables. With this method it is possible to control for within-subject correlated data, as is the case for subjects that had treatment for both legs. Co-

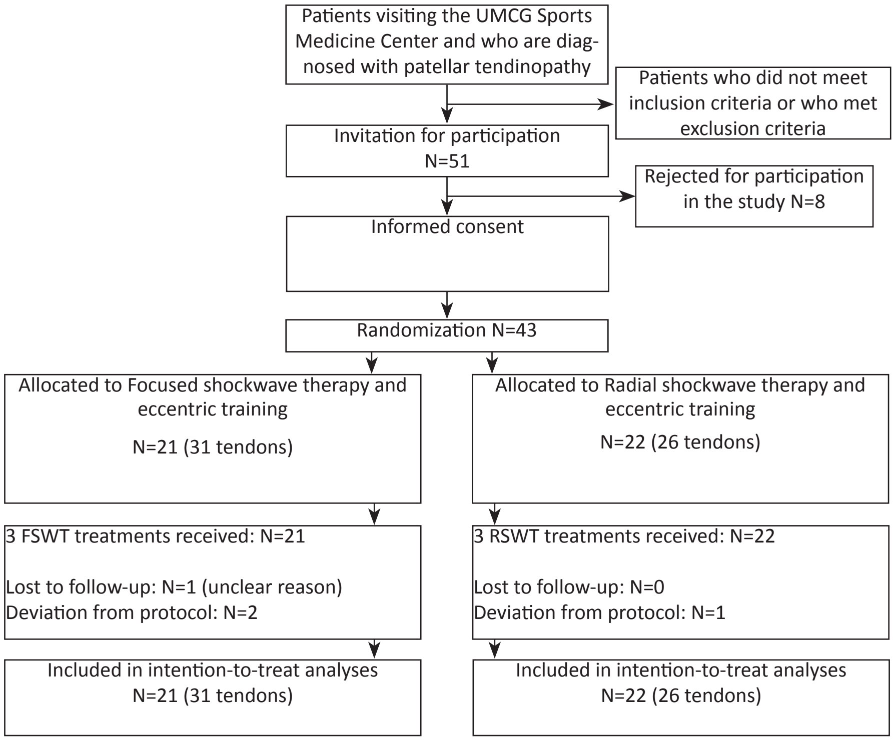

Figure 1. Flow of participants

variates included in the analyses were: duration of symptoms, hours of training during the first 5 weeks of the study, number of match events during the first 5 weeks of the study, number of days per week that the eccentric training program was performed, and the baseline value of the dependent variable. Chi-square tests were performed for discrete variables. Baseline, treatment and logbook data were analyzed using independent sample t-tests.

Results

Forty-three subjects (57 tendons) were randomized over the two treatment groups (Figure 1). Bilateral symptoms were present in 14 subjects. Twenty-one subjects (31 tendons) were treated with FSWT and 22 subjects (26 tendons) with RSWT. Subject characteristics are shown in Table 1. One subject dropped out of the study after the first follow-up. One subject (FWST) received an injection with corticosteroids in the tendon at his own request, after being told of the risks and side effects. Another subject (RSWT) received an injection with corticosteroids in the infrapatellar bursa. Both injections were given between the last treatment and the final follow-up. For these two subjects the values of the last measurement before the injection were carried forward. For three subjects the ESWT protocol had to be adjusted because they could not tolerate the pain (Figure 1). In the FSWT group, one subject received all treatments at an intensity of 0.07 mJ/mm^2 instead of 0.12 mJ/mm^2 and for one subject the intensity was adjusted to 0.10 mJ/mm^2 but only during the first treatment. For one subject in the RSWT group the intensity was adjusted during the first treatment from 2.4 bar to 1.8 bar. Treatments 2 and 3 were administered according to the protocol. All participants were included in the analyses (intention-to-treat).

Primary outcome measure

There was no difference between treatment groups in improvement on the VISA-P questionnaire after 14 weeks (p=.30), or any other time point. The main analysis showed that the FSWT group (15.0 points) as well as the RSWT group (9.6 points) improved significantly on the VISA-P questionnaire (p<.01; Table 2).

Secondary outcome measures

There were no significant differences in the amount of improvement on pain during ADL, pain during sport and pain during performance of the decline squat between treatment groups (Table 2). Both groups improved significantly over time on these measures. There was no difference between the FSWT and the RSWT group in the percentage of subjects that indicated improvement of symptoms after 7 weeks (60% vs. 59%, χ^2=0.04, p=.95, based on the 42 subjects that completed the study) and 14 weeks (65% vs. 75%, χ^2=0.29, p=.59; based on the 42 subjects that completed the study). There was no difference in pain experienced during the shockwave treatment between the FSWT and the RSWT group (VAS score: 4.9 (2.3) vs. 4.2 (2.5), p=0.32).

Logbook

The amount of training during the first 5 weeks of the study was 2.5 (2.9) and 1.6 (1.4) hours per week for the FSWT group and the RSWT group respectively (p=.24). The number of match events during the first 5 weeks was 0.04 (0.10) events per week for the FSWT group and 0.11 (0.27) for the RSWT group (p=.26). Participants reported that they performed the 5-days/week eccentric exercise program on average on 3.6 (1.9) days per week (FSWT group 3.2 (2.2) days per week; RSWT group 3.8 (1.6) days per week; p=.32).

Table 1. Baseline characteristics of the subjects.

	FSWT n=21 (tendons = 31) (Mean (SD))	RSWT n=22 (tendons = 26) (Mean (SD))	Total Group n= 43 (tendons = 57) (Mean (SD))	Difference between groups (p-value)
Age (years)	28.8 (10.3)	33.4 (10.7)	31.1 (10.7)	.16
Men/women	16/5	16/6	32/11	
Height (cm)	182.2 (8.8)	180.5 (8.5)	181.3 (8.6)	.52
Weight (kg)	80.5 (10.3)	78.4 (15.6)	79.4 (13.2)	.61
BMI	24.2 (2.5)	23.9 (3.8)	24.1 (3.2)	.78
Training h/wk	3.3 (4.1)	1.8 (1.6)	2.5 (3.2)	.13
Playing and training load compared to before injury: same load/reduced load	4/17	4/18	8/35	
Duration of symptoms (in months for all tendons)	32.3 (28.7)	38.6 (56.9)	35.2 (43.5)	.59
Unilateral/Bilateral	11/10	18/4	29/14	
Location of pain (proximal/midtendon/distal)	30/0/1	23/0/3	53/0/4	.22
Primary sport	5 soccer/3 basketball/2 running/2 volleyball/1 BMX/1 field hockey/1 fitness/1 handball/1 jiujitsu/1 MMA/1 rowing/1 tennis/1 no sport	6 running /6 volleyball/4 soccer/2 fitness/1 cycling/1 korfball/1 tennis/1 ultimate frisbee		

Table 2. Outcome measures at baseline and during follow-up for both treatment groups.

Measure	Time	FSWT (Mean (SD))	RSWT (Mean (SD))	Difference with pre-treatment (95% CI)[1]		Sig.
VISA-P	Baseline	48.6 (18.7)	48.8 (17.2)			
	1 week	53.7 (17.2)	53.9 (16.0)	0.0	(-7.4 to 7.5)	.99
	4 weeks	54.1 (16.3)	58.1 (18.2)	-3.8	(-10.7 to 3.1)	.34
	7 weeks	59.6 (16.9)	53.5 (21.5)	6.3	(-1.2 to 13.9)	.15
	14 weeks	63.6 (24.2)	58.4 (22.1)	5.4	(-3.8 to 14.6)	.30
VAS - ADL	Baseline	3.9 (2.4)	3.7 (2.3)			
	7 weeks	2.7 (2.1)	2.8 (2.3)	0.4	(-1.1 to 1.8)	.66
	14 weeks	2.0 (2.0)	2.1 (2.1)	0.3	(-0.9 to 1.5)	.65
VAS - sport	Baseline	6.1 (2.6)	6.0 (2.4)			
	7 weeks	4.6 (3.0)	4.4 (2.8)	0.0	(-1.1 to 1.1)	.99
	14 weeks	3.3 (3.0)	4.0 (2.6)	0.9	(-0.2 to 2.0)	.18
VAS - 1 single-leg decline squat	Baseline	3.3 (3.4)	3.5 (2.3)			
	7 weeks	2.5 (3.3)	3.2 (2.5)	0.5	(-0.6 to 1.6)	.42
	14 weeks	2.5 (3.4)	2.4 (2.6)	-0.3	(-1.5 to 0.8)	.61
VAS - 10 single-leg decline squats	Baseline	4.4 (3.3)	4.1 (2.2)			
	7 weeks	3.2 (3.5)	3.6 (2.6)	0.7	(-0.4 to 1.7)	.28
	14 weeks	3.4 (3.5)	3.0 (2.7)	-0.1	(-1.1 to 1.0)	.92

[1] Positive values for the differences indicate a larger improvement for the FSWT group

Discussion

This is the first randomized controlled trial to compare the effectiveness of FSWT and RSWT in the treatment of PT. This study, with a previously published transparent design, found no differences in effectiveness of FSWT or RSWT for treating PT. Both groups improved significantly over the 14-week follow-up period, but there were no differences between groups in VISA-P scores, in VAS pain scale scores or in the rating of subjective improvement. There were no differences between groups in pain experienced during the treatment either. For this reason it is impossible to recommend one treatment over the other based on outcome of treatment or feasibility.

Overall, the effectiveness of ESWT for PT remains a matter of debate.[1] A recent systematic review of the literature on the effectiveness of ESWT identified studies that had rather good treatment results but a variable methodological quality. Based on this literature it was concluded that ESWT seems to be a safe and promising treatment for PT.[3] However, a more recent RCT found no effect of ESWT for

patellar tendinopathy. The improvement of 15.0 and 9.6 points for the FSWT and RSWT group respectively on the primary outcome measure of the present study, the VISA-P questionnaire, was also rather disappointing, as we defined a change of 15 points as the minimal clinically relevant difference. More randomized trials with a transparent design studying different treatment protocols are therefore necessary to determine the exact role of ESWT as treatment option for PT.
The aim of the present study, however, was not to answer the question of whether ESWT is effective for PT but to compare the effectiveness of two ESWT methods. The choice for this research question was motivated by the discrepancy we have previously noted between "science", in which mainly the effectiveness of FSWT is studied, and "practice", where primarily RSWT devices are used by practitioners and physical therapists in the Netherlands.[8] One might expect a difference in effectiveness because of the differences between the technologies of FSWT and RSWT. Despite this, there are no in-vitro studies available that compare the biological effects of both methods and there is only one clinical study that has previously compared the clinical effects of FSWT and RSWT. In that study subjects with plantar fasciitis received either three sessions of either FSWT or RSWT with the same device as in the present study.[14] A very small difference on a pooled outcome measure in favor of FSWT was found. This pooled measure was a combination of eight variables, including the functional foot index and neuromuscular performance tests. Because of this pooling of variables it is difficult to understand what this difference means, and it is also questionable whether this difference has clinical relevance. On theoretical grounds, a difference in favor of FSWT might have been expected since the plantar fascia is a thick tissue that is located deeper into the body and FSWT is supposed to act deeper than RSWT. The same hypothesis can be applied to PT, since the most common location for PT is the proximal posterior part of the patellar tendon.[15] In the present study, however, no differences were found between FSWT and RSWT either. Based on the study by Lohrer et al. (2010) and the present study, at the moment there is no evidence of clinically relevant differences in effectiveness between the two ESWT technologies.
For these reasons, other aspects may have to be considered in the decision of which device to use. One such consideration may be the amount of pain that is experienced by subjects during treatment. In the present study we found no difference in the pain experienced during FSWT and RSWT. A difference would have been obvious, since it is known that the experienced pain is related to the pressure field generated by the ESWT device,[16] and the pressure fields of the two ESWT

technologies are very different. Then there is the economic aspect to consider. A calculation of the costs for both methods shows that the costs of RSWT are lower than those of FSWT (personal communication with supplier, January 2012). Variable costs for an RSWT treatment of 2000 pulses are around 20% of the costs of FSWT. The yearly depreciation costs are also lower for RSWT, around 70 % of those of FSWT.

Our study has some strength and limitations. Strengths where the use of a randomized controlled design, the fact that the design was previously published, blinding of patients as well as outcome assessors, use of multiple outcome measures, and application of both FSWT and RWST with the same equipment. Another strength is that subjects completed a weekly logbook, with results that indicate that instructions to reduce load during the first weeks of the trial were followed. A limitation was that no firm conclusions can be drawn with regard to the effectiveness of ESWT because no placebo or control group was studied. Another limitation is that treatment results might be influenced by the fact that more subjects in the FSWT group had bilateral PT. It has been suggested that there are differences in the etiology of unilateral and bilateral PT,[17-19] although others found no differences between these populations.[20] Even if there are differences in etiology though, this does not necessarily mean that the treatment would affect subjects with unilateral and bilateral PT differently. By using GEE as a statistical method we controlled for the fact that some of the subjects were treated on both legs. This is often omitted in studies that treat subjects on two limbs, and it may bias the results as scores of the limbs of one subject are correlated.[21, 22]

In conclusion, there is no difference between FSWT and RSWT for chronic PT in addition to eccentric training. Both treatment groups showed a slight improvement after treatment, although it is questionable whether this difference is clinically relevant. Based on the present clinical results it is impossible to recommend one ESWT treatment over the other in term of effectiveness, but on economic grounds RSWT seems to be more cost-effective.

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Chapter 9

General Discussion

Introduction

Prevention and treatment of patellar tendinopathy (PT) are important because this injury has a high prevalence in jumping athletes.[1, 21] The general objective of this thesis is therefore to increase knowledge of both prevention and treatment of PT. The first part of the thesis (Chapters 2 – 5) addresses the etiology of PT, since such knowledge is an important step towards prevention. The second part (Chapters 6 – 8) addresses Extracorporeal Shockwave Therapy (ESWT) as a treatment for PT. This general discussion starts out with a summary of the main findings of the research presented in this thesis. Next, these findings are discussed in relation to the prevention and management of PT. This constitutes the basis for some practical suggestions given for trainers, coaches and clinicians. The chapter ends with a general conclusion.

Findings of this thesis

The first aim of this thesis was to increase understanding of the etiology of PT. Understanding the development of an injury by uncovering risk factors is one of the steps towards its prevention.[3] The first part of this thesis reviews the literature concerning risk factors for PT (Chapters 2 & 3). Chapter 2 addresses risk factors related to demographics, anthropometrics and sports, while Chapter 3 addresses risk factors related to jump biomechanics. A survey was also conducted to study risk factors in a large group of non-elite athletes as well as the relation between occupational risk factors and PT (Chapters 4 & 5). Based on the findings of the first part of this thesis it appears that PT has a multifactorial etiology and that no definite answers can be given yet as to what factors pose the most threat to developing it. Nonetheless a number of risk factors were identified that have a high potential for being used for preventive purposes as well as in the clinic to guide the search for causative factors in individual cases. Risk factors identified were: weight, BMI, waist-hip ratio, leg-length difference, arch height of the foot, quadriceps flexibility, hamstring flexibility, quadriceps strength, vertical jump performance (Chapter 2), stiff landing pattern (Chapter 3), age, gender, playing position in volleyball players (Chapter 4) and heavy physically demanding work (Chapter 5). Another finding was that PT can have an impact on work performance and productivity (Chapter 5), which further stresses the relevance for society of developing preventive measures. The second aim of this thesis was to study ESWT as a treatment for PT with a special focus on the differences between the two types of ESWT: focused shockwave therapy (FSWT) and radial shockwave therapy (RSWT). These differences are described in Chapter 6. Each type of ESWT uses a different technology to generate therapeutic waves, which makes the resulting therapeutic waves dissimilar. Focused shockwaves penetrate deeper into the tissue than radial shockwaves, and each technology generates waves with different properties. It is unclear whether these differences between FSWT and RSWT are also reflected in terms of therapeutic efficacy. For this reason, the TOPSHOCK study, a randomised controlled trial (RCT) was designed to compare these two types of ESWT for treating PT (Chapter 7). No differences on any of the outcome measures were found between treatment with FSWT and treatment with RSWT after 14 weeks (Chapter 8), so there is no outcome-related reason to prefer one technology over the other. There may be corporate financial reasons to make a choice though. Overall, treatment with both types of ESWT combined with eccentric exercises resulted in a moderate improvement in patients with PT.

Figure 1. The Translating Research into Injury Prevention Practice (TRIPP) framework. (Reprinted from Journal of Science and Medicine in Sport, Volume 9, Finch, A new framework for research leading to sports injury prevention, 3-9, 2006, with permission from Elsevier.)

Prevention of patellar tendinopathy

Prevention of overuse injuries in sports is important, since they have a high prevalence and are often difficult to treat. Especially PT is a common troublesome injury for which treatment results are quite variable. Conducting effective research into the prevention of sports injuries requires a conceptual model. According to such a model, the Translating Research into Prevention Practice (TRIPP) framework developed by Finch (2006),[3] prevention of sports injuries can be achieved through a 6-stage approach (figure 1).

The first stage of the framework addresses injury surveillance, that is, establishing the extent of the problem. Studies examining this stage have shown that PT is common in sports that involve jumping, especially basketball and volleyball.[1, 2, 4] The literature focusing on the second stage of the TRIPP framework, understanding the etiology, is extensive. However, because of the heterogeneity of this literature it is difficult to come to a complete understanding of the etiology. The first part of the present thesis aimed at increasing this understanding by reviewing the literature, and conducted a survey among basketball and volleyball players. A number of possible risk factors were identified on this basis. Since most of the current understanding of the etiology is based on cross-sectional studies, future studies should preferably have a prospective design in order to identify causal relations between risk factors and PT. Two recent examples of this are a prospective study showing that reduced ankle dorsiflexion range may be a risk factor for patellar tendinopathy,[5] and a prospective study that concluded that training volume is a risk factor for patellar tendinopathy.[6]

In the third stage of the TRIPP framework, potential solutions to the injury problem are identified based on the modifiable risk factors identified in stage 2. Based on the risk factors identified in Chapter 2–5 of this thesis, prevention (and recovery) may be achieved by reducing body weight, increasing upper-leg flexibility and strength, prescribing orthotics to address a low foot arch and leg-length differences, changing playing position, avoiding heavy physically demanding work and employing a flexible landing style. In other words, reducing and adapting load seems to be crucial.

In stage 4 scientific evaluation of these preventive measures can be done under controlled conditions. At present there is almost no research available that addresses this stage. Only one study has looked at the effectiveness of a preventive (balance training) program on the incidence of PT.[7] The preventive measure in this study, a balance training program, was not based on research addressing the second stage of the framework, as there is no literature available that has shown a link between PT and poor balance skills. Not following the stages of the TRIPP framework decreases the chances of finding effective preventive measures and lacks an explanation of why such an intervention works. As stage 4 is scarcely studied and almost no effective preventive measures have been identified, stages 5 and 6 of the TRIPP framework, both related to implementation, have not yet been addressed in relation to PT.

Future research

For now, research into the prevention of PT should focus on two stages. To begin with, there is a need for (prospective) studies that further address risk factors for PT (stage 2), the first part of this thesis is a first step in this direction. Secondly, there is a need for studies that develop preventive measures based on the already identified risk factors (stage 3) and which test these preventive measures under controlled conditions (stage 4). Based on the findings in the present thesis and a recent study, a likely candidate for such a preventive measure is kinetic chain functioning. The literature suggests that both upper-leg flexibility and ankle flexibility play a role in the onset of PT,[5, 8, 9] so addressing the kinetic chain function (e.g. improving ankle flexibility) may be an option for prevention. Another possibility may be the development of a program to teach athletes a landing style that is more flexible and places less stress on the patellar tendon.

Management of patellar tendinopathy

A critical review by Gaida and Cook (2011) concluded that eccentric decline squat training is currently the preferred first-line treatment.[10] The idea that eccentric exercise is more beneficial for PT compared to concentric exercise has recently been challenged by a study showing that heavy slow resistance training (with both concentric and eccentric movement) was more effective than eccentric decline squat training.[11, 12] Slow speeds thus seem to be crucial when performing exercises, irrespectively of whether they are concentric, eccentric or both.[11, 13, 14] Future research into exercise-based rehabilitation should study load management – the relation between the amount of load that is placed on the tendon and the load capacity of the tendon. This is important because it is known that both overuse and disuse can have a negative effect on the tendon. Gaining knowledge about what amount of load is beneficial may improve exercise-based rehabilitation.

In subjects with recalcitrant PT who already have tried to modify risk factors and

do not respond to exercise treatment, ESWT may be an option before trying more invasive options such as surgery. A difficulty with studying the effectiveness of ESWT is that there are numerous parameters (Chapter 6) that can be varied in ESWT, and that may potentially influence the results. The present thesis aimed at clarifying one of these parameters, the technology that is used: FSWT or RSWT. No differences were found in the effectiveness of these two technologies for treating PT (Chapter 8), despite the differences between them (Chapter 6). Based on these findings it is not possible to recommend one treatment over the other.
A systematic review of the literature on ESWT for PT found several mostly low-quality studies with positive results, concluding that ESWT is a safe and promising method for treating PT but that further research was required.[15] A more recent high-quality RCT showed found no effect of ESWT: athletes in this study kept on training and playing and had symptoms for less than 12 months, which may explain the poor results.[16] In the present thesis (Chapter 8) these factors were taken into account by prescribing relative rest to the subjects and by including subjects that on average had complaints for almost three years. Still, treatment with ESWT resulted in only a moderate improvement. It can therefore be concluded that ESWT is not the panacea for patellar tendinopathy it is sometimes claimed to be. Future randomised placebo controlled studies should further address the effectiveness of ESWT taking into account the parameters that can be varied. At present, ESWT does not seem to be the first choice when treating PT. Other treatment options for PT may be more preferable. Gaida and Cook (2011) suggest sclerosing injections or arthroscopic shaving when conservative treatment is not successful,[10] although the number of studies on which this suggestion is based is small. All treatments for PT, conservative as well as more invasive, have in common that treatment results are variable and patients do not always become totally asymptomatic. Hence the slogan that 'treatment effectiveness is inversely proportional to the number of available treatment choices' seems to be applicable to PT.[10]

Future research

All of this raises the question of how we can arrive at more effective treatments for PT. A first requirement would be a thorough understanding of the etiopathogenesis and pathophysiology of PT and of how pain is caused in tendinopathy. There are still gaps in our knowledge concerning these topics though. For example, with regard to the etiopathogenesis there is no consensus as to what causes patellar tendinopathy. Is the injury caused by overloading or underloading of the tendon?

According to the mechanical theory, overload of the tendon may lead to onset of pathology,[17] while others have suggested that it is initially underloading of the tendon, secondary to micro-trauma, which leads to pathology.[18] There is no consensus either as to which forces cause PT, given that both tensile and compressive forces have been implicated in its onset.[19] These etiopathogenesis issues may have implications for the management of PT. The pathophysiology of the condition is not fully understood either, especially when the tendon enthesis is concerned. Without a better understanding of the pathology, treatment of PT remains a black box. Further understanding of the pathophysiology may lead to the development of new treatments approaches. Part of a solution to this problem may be found in a model developed by Cook and Purdam (2009) that describes tendinopathy as having several stages.[20] Their model distinguishes three stages of pathology that form a continuum: *reactive tendinopathy, tendon disrepair* and *degenerative tendinopathy*. This continuum model does justice to the observation that there are varieties in tendinopathy and to the possibility that certain treatments are only effective during certain stages. For example, applying load may be beneficial during the tendon disrepair stage but not during reactive tendinopathy, where load reduction is more appropriate. This model gives new insights into the pathology underlying PT and may help increase the effectiveness of treatments. Problems with the continuum model are that it is still to a certain extent hypothetical, it may be difficult to differentiate between stages in practice and several stages of tendinopathy may be present in one single tendon. Another gap in the knowledge of PT is how the pain is caused.[21] Closing these gaps in our understanding is important to arrive at effective treatments.

Besides the lack of understanding of the pathology underlying PT, methodological issues may also be a reason for the dearth of effective evidence-based treatments. First, PT is a clinical diagnosis. There is currently no gold standard (except for histological analyses) for diagnosing PT. Imaging with MRI and ultrasound may help establish a diagnosis, but clinical diagnosis and imaging do not always agree.[22] Because of this, study populations may be heterogeneous and a treatment may only be effective in only part of a study population. Second, recording overuse injuries in sports is difficult.[23] Whereas recording time loss is appropriate in acute injuries, it is less applicable to chronic overuse injuries. Instruments that measure reduction of function are better suited for these chronic cases. The VISA-P questionnaire is such an instrument and is at the moment the first choice in effectiveness studies. However, there is also a need for objective measures of pathology in PT, as symptoms can disappear while the pathology is still present (iceberg phenomenon). A more objective outcome measure may therefore increase the chances of finding effective treatments. When these two methodological issues are addressed in combination with the development of a more thorough understanding of the injury itself, the likelihood of finding more effective treatments increases.

What is the relevance of these findings for trainers, coaches and clinicians?

The aim of this section is to try to translate the findings presented in this thesis into some practical suggestions that can be used by trainers, coaches and clinicians. It is always difficult to directly translate research findings into practical applications. It should therefore be stressed that these are only suggestions.

The following practical recommendations can be given to trainers and coaches:

- Workload should be taken into account when designing a training program. Especially people who have a physically demanding job may need some adaptation of their training program to avoid overloading.
- Young athletes should be trained to employ a flexible landing style.
- Volleyball players who develop PT or who have a high risk for developing it may consider switching to a playing position that poses a lower risk for PT, such as setter or libero.

The following practical recommendations can be given to clinicians:

- Reducing body weight, increasing upper-leg flexibility and strength, prescribing orthotics to address a low foot arch and leg-length differences, changing playing position, avoiding heavy physically demanding work, and employing a flexible landing style may be factors to address in the treatment of PT. Recent studies have shown that a reduced ankle dorsiflexion range and training volume are other factors that should be considered.
- When managing load and load capacity, workload should also be taken into account.
- ESWT should not be the first option of choice to treat PT.
- There is currently no evidence that shows an advantage in effectiveness for one of the two ESWT technologies (FSWT and RSWT), therefore corporate financial considerations should prevail.

Jumper's knee: A patient's story – part II

At the moment I am playing volleyball again and am enjoying it! Last year I wouldn't have thought that I'd ever able to return to the game without pain. When I went to the sports medicine physician he explained to me the importance of the balance between load and load capacity. The rehabilitation program I got focussed on kinetic chain functioning, such as core stability exercises and stretching, and strength training at slow speeds. The intensity of the program was increased slowly. We also tried ESWT but I'm not sure if it helped much. When I was ready to start with sport-specific exercises I was advised to focus on landing as softly as possible. I moved back to my previous team because playing at a lower level also means less training, and the increase in training was probably one of the causes of my complaints. I was also told that a change of playing position might help me. I always used to play as an outside hitter. Although it was a difficult decision, I decided to change to the libero position. This means I have to jump less, which is the activity that provoked the pain. As I also experienced pain during my work as a waiter, I decided to quit that job and find something that is less physically demanding. I now found a job in the telemarketing business. So, although I now play at a lower level and I am not playing on the field position I was used to, I'm actually quite happy. Next time I have similar symptoms I will reduce my training load earlier.

Conclusions

The general objective of this thesis was to improve prevention and treatment of PT. The first aim was to increase knowledge of the etiology of PT. Based on the studies presented in this thesis, a number of risk factors were identified. These risk factors should be taken into account for prevention as well as treatment of PT, and they should also be a starting point for future studies.

The second aim was to increase knowledge of ESWT as a treatment, specifically with respect to the differences between FSWT and RSWT. Several differences between the two technologies have been identified in the literature, but they do not seem to affect the therapeutic efficacy for PT.

The present thesis meets its general objective of providing new insights towards improving prevention and treatment of PT. As is often the case, this thesis also ends with the observation that more research is required. This future research should be directed at a further understanding of the etiology and pathophysiology of PT as well as its treatment. This last point also involves understanding the working mechanism of a treatment. Up until now, the treatment of PT has been too much like applying a black box (the treatment) to another black box (the pathology). Only by opening up these black boxes can effective evidence-based treatments for this recalcitrant injury be developed.

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Summary

Patellar tendinopathy (also called jumper's knee) is a common injury in sports that involve jump actions such as volleyball and basketball. In elite and recreational basketball players the prevalence is 32% and 12% respectively and in elite and recreational volleyball players it is 45% and 14% respectively. This high prevalence together with the observation that this injury often causes long lasting symptoms stresses the importance of finding effective ways to prevent this injury and, for cases where prevention fails, to develop effective treatments. These two subjects, prevention and treatment of patellar tendinopathy (PT), are the focus of this thesis (**Chapter 1**).

The aim of the first part (**Chapter 2 – Chapter 5**) of this thesis, that addresses prevention, is to increase knowledge about the etiology of PT. Understanding the etiology of an injury is one of the steps towards developing effective preventive measures. This first part starts out with giving an overview of the literature (**Chapters 2 & 3**). In **Chapter 2** a systematic review of literature concerning risk factors for PT is performed. The systematic search resulted in the inclusion of 11 studies that addressed risk factors for PT in athletes. The methodological quality of these studies was assessed and based on this assessment a strength of evidence criterion was applied to identify risk factors. The overall methodological quality of the included studies was low. Therefore the level of evidence for the identified risk factors was also so low. Nine risk factors were identified for which there is some evidence that they are related to PT. These are weight, body mass index, waist-to-hip ratio, leg-length difference, arch height of the foot, quadriceps flexibility, hamstring flexibility, quadriceps strength and vertical jump performance. Based on this literature review, recommendations are given as to what may be options for prevention and treatment of PT. These are reducing body weight, increasing upper-leg flexibility and quadriceps strength and the use of orthotics. A biomechanical approach is taken in **Chapter 3**. Biomechanical risk factors are identified by a systematic review of literature that addresses the relation between PT and jumping. Nine articles were identified from the literature. A synthesis of these studies suggests that risk factors for PT are flexion angles (small ankle plantar flexion angle, large knee flexion angle) at touchdown that reduce the available range of motion, a small range of motion and high angular velocities. Furthermore, landing seems to pose a greater threat for developing PT than take-off. This suggests that employing a flexible landing strategy may help prevent PT, although there is a need for prospective studies on this topic.

The results of a survey to identify risk factors among basketball and volleyball play-

ers are presented in **Chapters 4 and 5.** The aim was to identify risk factors in a large representative sample of basketball and volleyball players since most research in the past has been done on specific groups (e.g. only elite players) and has used small sample sizes. An online survey was sent to the playing members of the Dutch Basketball Association (NBB) and the Dutch Volleyball Association (NEVOBO). The survey consisted of questions concerning 1) subject characteristics, 2) knee injuries and PT, 3) sports participation and 4) occupation. The survey was send to approximately 12000 subjects. The response rate was around 20%. Based on 2224 subjects it was found that risk for PT decreased with age, was higher in subjects who play at the national level, was higher in men compared to women and was higher in volleyball players compared to basketball players (**Chapter 4**). In volleyball players, playing as outside hitter or middle blocker was found to increase the chance of developing PT compared to playing as setter. For basketball players no playing positions with an increased risk were identified. These findings should be taken into account for prevention and rehabilitation. After excluding students, occupational risk factors for PT were assessed in 1505 subjects (**Chapter 5**). Heavy physically demanding work was found to be a risk factor for PT. The odds in subjects with heavy physically demanding work was twice as high as in subjects with mentally demanding work (e.g. an office job). Especially food and beverage workers and professional basketball and volleyball players showed a high risk. It was also found that PT can have a considerable impact on work productivity and can cause work limitations. These findings suggest that PT is not only a sports injury, but to a certain extent also an occupational disease. Work load should be taken into account when treating PT.

The second aim of this thesis is to gain knowledge about Extracorporeal Shockwave Therapy (ESWT) as a treatment for PT and more specifically about the differences between focused and radial ESWT. The second part of this thesis (**Chapter 6 – Chapter 8**) is about this second aim. There are a number of differences between these two ESWT technologies (**Chapter 6**); focused ESWT (FSWT) and radial ESWT (RSWT). One difference is the technology that is used to generate the therapeutic waves. This difference in technology leads to differences in the characteristics of the therapeutic waves that are generated with both methods. It is even argued in the literature that waves that are generated with RSWT are not real shockwaves because these waves lack the typical characteristics of shockwaves. There are also differences between technologies in the location where the waves reach their maximal intensity. Whereas focused shockwaves reach their maximal intensity (and theoretically their maximal therapeutic effect) in the focus that is located deeper in the tissue, radial shockwaves reach their maximal intensity at the contact surface at the skin. However, it is not clear what these differences mean for therapeutic efficacy. This, together with the observation that most clinicians and physical therapists in the Netherlands, who use ESWT to treat PT, use a radial shockwave device, while on the other hand most research that has been conducted on this subject used focused shockwave devices, was the motive to design a study that directly compares both methods. In **Chapter 7** the design of this study, the TOPSHOCK study, that directly compares FSWT and RSWT is described. The TOPSHOCK study is a randomized controlled trial with two groups. One group received 3 treatments with FSWT while the other group received 3 treatments with RSWT. Subjects as well as outcome assessors were blinded to the allocation of the treatment. Both groups also executed an eccentric exercise program that started two weeks after the final treatment. The main outcome measure was the VISA-P questionnaire that measures pain, function and sports participation in subjects with PT. Measurements took place before the treatment and 1, 4, 7 and 12 weeks after the final treatment.

The results of the TOPSHOCK study are presented in **Chapter 8**. No differences were found between the FSWT group and the RSWT group on the VISA-P questionnaire (15.0 vs. 9.6 points) after 12 weeks. Both groups did improve significantly over time, but it is debatable whether this represents a clinical relevant change. There were also no differences between groups on the other outcome measures. Based on these results it is not possible to recommend one of the two types of ESWT over the other.

The general discussion in **Chapter 9** starts out with an overview of the findings presented in this thesis. Next, these findings are discussed in relation to the two main topics of this thesis: prevention and treatment. At the end of this chapter some practical suggestions for trainers, coaches and clinicians are extracted from the findings that are presented in this thesis.

Samenvatting

Patella tendinopathie (ook wel jumper's knee of springersknie genoemd) is een veel voorkomende blessure in sporten waarin veel wordt gesprongen, zoals basketbal en volleybal. In top- en recreatieve basketballers is de prevalentie respectievelijk 32% en 12% en in top- en recreatieve volleyballers respectievelijk 45% en 14%. Deze hoge prevalentie, samen met het feit dat deze blessure vaak langdurige symptomen oplevert, geeft het belang aan van het vinden van effectieve manieren om deze blessure te voorkomen, en voor gevallen waarin dit niet lukt, effectieve therapieën te ontwikkelen. Deze twee thema's, preventie en behandeling van patella tendinopathie (PT), staan centraal in dit proefschrift (**Hoofdstuk 1**).

Het doel van het eerste deel van dit proefschrift (**Hoofdstuk 2-5**), dat gaat over preventie, is om de kennis over de etiologie van PT te verbeteren. Begrip van de etiologie is een van de stappen naar het ontwikkelen van effectieve preventiemaatregelen. Dit deel begint met het geven van een overzicht van de literatuur (**Hoofdstuk 2 en 3**). In **Hoofdstuk 2** wordt een systematisch literatuuronderzoek naar risicofactoren voor PT beschreven. In het systematische literatuuronderzoek werden 11 studies geïdentificeerd naar risicofactoren voor PT in sporters. De methodologische kwaliteit van deze studies was laag. Negen risicofactoren werden gevonden waarvoor enig bewijs is dat ze een relatie hebben met PT. Dit waren gewicht, Body Mass Index (BMI), middel-heup ratio, beenlengteverschil, voetbooghoogte, quadricepsflexiblilteit, hamstringflexibiliteit, quadricepskracht en verticale spronghoogte. Op basis hiervan wordt een aantal aanbevelingen gegeven voor preventie en behandeling van PT, zoals het verminderen van lichaamsgewicht, verbeteren van de bovenbeenflexibiliteit en quadricepskracht en het gebruik van orthosen. Een meer biomechanische benadering wordt beschreven in **Hoofdstuk 3**. In een systematisch literatuuronderzoek naar de relatie tussen PT en springen worden biomechanische risicofactoren geïdentificeerd. Negen studies werden gevonden in de literatuur. Op basis van een synthese van deze studies worden de volgende risicofactoren gesuggereerd voor het ontstaan van PT: een flexiehoek op het moment van eerste grondcontact die de beschikbare range of motion vermindert (zoals een kleine plantairflexiehoek en een grote kniehoek), een kleine range of motion en hoge hoeksnelheden. Daarnaast lijkt de landing een groter risico te vormen dan de afzet. Het lijkt er dus op dat het gebruik van een flexibele landingsstrategie PT kan helpen voorkomen, maar er is een behoefte aan verder prospectief onderzoek naar dit onderwerp. De resultaten van een survey naar risicofactoren voor PT onder basketballers en volleyballers worden beschreven in **Hoofdstuk 4 en 5**. Het doel was om risicofactoren te identificeren in een grote representatieve groep basketballers en volleyballers, omdat tot nu toe het onderzoek met name werd uitgevoerd onder specifieke groepen (bv. topspelers) en met kleine steekproefgrootten. Een online vragenlijst werd naar de spelende leden van de Nederlandse Basketbal Bond (NBB) en Nederlandse Volleybal Bond (NEVOBO) gestuurd. De vragenlijst bestond uit vragen over 1) persoonlijke kenmerken, 2) knieblessures, 3) sportbeoefening en 4) werk. De vragenlijst werd aan ongeveer 12000 personen gestuurd. Het responspercentage lag rond de 20%. Op basis van een analyse van 2224 personen bleek dat het risico voor PT afnam met leeftijd, hoger was voor spelers die op nationaal niveau speelden, hoger was voor mannen dan voor vrouwen en hoger was voor volleyballers dan voor basketballers (**Hoofdstuk 4**). Een verhoogd risico werd gevonden voor volleyballers die spelen als buiten- of middenaanvaller in vergelijking met volleyballers die spelen als spelverdeler. Voor basketballers werden geen speelposities met een verhoogd risico gevonden. Deze bevindingen zouden meegenomen moeten worden voor preventie- en revalidatiedoeleinden. Na het excluderen van studenten werden werkgerelateerde risicofactoren vastgesteld bij 1505 personen. Zwaar lichamelijk belastend werk bleek een risicofactor voor PT te zijn. De kans op het krijgen van PT bij personen met zwaar lichamelijk werk bleek twee keer zo hoog te zijn in vergelijking tot personen met mentaal belastend werk (bv. een kantoorbaan). Vooral personeel in de horeca en professionele basketballers en volleyballers vertoonden een verhoogd risico. Dit suggereert dat PT niet alleen een sportblessure is, maar in zekere mate ook een beroepsziekte is. Daarom moet werkbelasting ook worden meegenomen in de behandeling van PT.

Het tweede doel van dit proefschrift is om kennis te vergaren over Extracorporele Shockwave Therapie (ESWT) als een behandeling voor PT en in het bijzonder over de verschillen tussen gefocuste en radiale ESWT. Het tweede deel van dit proefschrift (**Hoofdstuk 6-8**) behandelt dit tweede doel. Er is een aantal verschillen tussen de twee ESWT technologieën (**Hoofdstuk 6**); gefocuste ESWT (FSWT) en radiale ESWT (RSWT). Eén verschil is de technologie die wordt gebruikt om de therapeutische golven te genereren. Dit verschil in technologie leidt tot verschillen in de karakteristieken van de opgewekte therapeutische golven die beide methoden opwekken. Er wordt in de literatuur zelfs betoogd dat de golven die met RSWT worden opgewekt, geen echte shockwaves zijn, omdat ze de typische eigenschappen van shockwaves missen. Er zijn ook verschillen tussen de beide technologieën in de plek waar de golven hun maximale intensiteit bereiken. Gefocuste shockwaves bereiken de maximale intensiteit (en theoretisch gezien het maximale therapeutisch effect) dieper in het weefsel, terwijl radiale shockwaves hun maximale intensiteit bereiken op de overgang naar de huid. Het is echter niet duidelijk wat deze verschillen betekenen voor de therapeutische effectiviteit. Dit, samen met het feit dat de meeste behandelaars in Nederland die PT behandelen RSWT gebruiken, terwijl het meeste wetenschappelijk onderzoek met FSWT is uitgevoerd, was de aanleiding om een studie op te zetten die beide technologieën vergelijkt. In **Hoofdstuk 7** wordt de opzet van dit onderzoek, de TOPSHOCK studie, dat de effectiviteit van beide methoden vergelijkt, beschreven. De TOPSHOCK studie is een gerandomiseerd gecontroleerde trial met twee groepen. Eén groep onderging drie behandelingen met FSWT en de andere groep onderging drie behandelingen met RSWT. Voor zowel patiënten als onderzoekers was tijdens het onderzoek onbekend welke shockwave-behandeling was toegewezen. Beide groepen voerden ook een programma met excentrische oefeningen uit dat twee weken na de laatste ESWT behandeling startte. De belangrijkste uitkomstmaat was de score op de VISA-P vragenlijst die pijn, functie en sportbeoefening meet bij personen met PT. Metingen vonden plaats voor de behandeling en 1 week, 4, 7 en 14 weken na de behandeling. De resultaten van de TOPSHOCK studie worden beschreven in **Hoofdstuk 8**. Er werden geen verschillen gevonden tussen de FSWT groep en de RSWT groep in vooruitgang op de VISA-P score (15.0 vs. 9.6 punten) na 14 weken. Beide groepen verbeterden significant in de tijd, maar het is betwistbaar of deze verbetering klinisch relevant is. Er waren ook geen verschillen tussen de twee groepen op de andere uitkomstmaten. Op basis van deze resultaten is het niet mogelijk om één van de twee typen ESWT aan te bevelen boven de andere.

De algemene discussie in **Hoofdstuk 9** begint met het geven van een overzicht van de bevindingen in dit proefschrift. Daarna worden deze bevindingen bediscussieerd in relatie tot de twee thema's die centraal staan in dit proefschrift: preventie en behandeling. Aan het eind van dit hoofdstuk worden een aantal praktische aanbevelingen gedaan voor trainers, coaches en clinici op basis van de bevindingen in dit proefschrift.

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Curriculum Vitae

Curriculum Vitae

Henk van der Worp was born in Zwolle on October 18, 1978. He spent most of his childhood living in Hoogezand. In September 2000 he began his studies in Human Movement Sciences at the University of Groningen and in 2004 earned his Master's degree. His Master's thesis was focused on the relationship between actual and mental movement time, and was performed under the supervision of Prof. dr. Theo Mulder. In September 2004, he started working as a junior researcher at the Center for Human Movement Sciences at the University of Groningen. The research undertaken in that period looked at the relation between imagined, observed and performed actions. Between October 2007 and August 2009, he worked at the Court of Law in Groningen. In September 2009, he began working as a PhD student at the Center for Sports Medicine of the UMCG, resulting in the research presented in this dissertation.

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